

**CANCER RISK ASSESSMENT OF ARSENIC TOXICITY ON
UTILIZATION OR STORAGE OF PULVERIZED FLY ASH FROM
MAE MOH LIGNITE POWER PLANT, NORTHERN THAILAND**

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MAJOR SARANYU VIRIYAVEJAKUL

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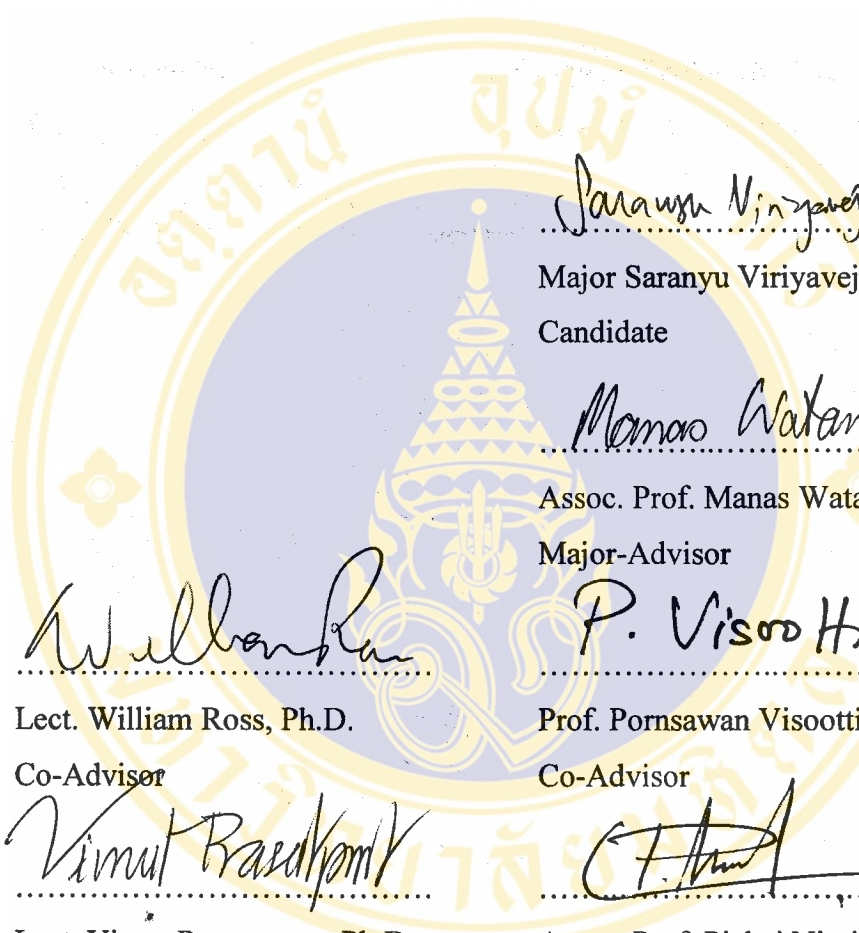
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MAE MOH LIGNITE POWER PLANT, NORTHERN THAILAND**



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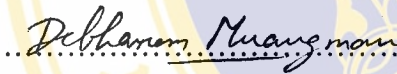
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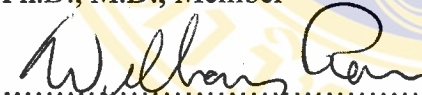
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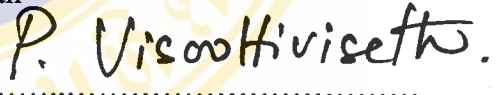
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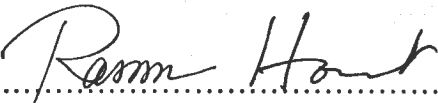
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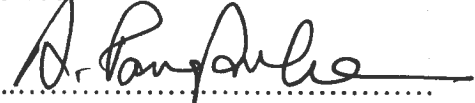
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Saranyu Viriyavejakul
September 2003

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ABSTRACT

This research investigates cancer risks from arsenic in Mae Moh fly ash. Currently the ash is either stored in a disposal site or sold for other uses. Three scenarios were modeled, along with three groups of populations. The three scenarios were current storage and sale of fly ash, complete storage of fly ash, and complete sale of fly ash. The three populations were occupational, residential, and user populations. Reasonable assumptions were made to simplify certain environmental settings. Best environmental model was applied to approximate total arsenic concentrations in media for each scenario, which was extrapolated from the concentrations of the current storage and sale of fly ash. The cancer risks were analyzed in accordance with international standards for human health risk assessment set by the United States Environmental Protection Agency. The study tests this hypothesis: ‘the overall cancer risk due to toxicity of total arsenic in fly ash when fly ash is utilized as construction material is less than when it is stored at a disposal site.’ Samples of fly ash, water, soils, and grasses were collected according to possible exposure pathways of ingestion, inhalation, and dermal contact for all scenarios and populations. They were then tested for cancer risks under a variety of methods. The modeling showed that in all scenarios and populations, both central tendency exposure and reasonable maximum exposure, were within acceptable limits, therefore no immediate remedial actions at this moment are legally required. The overall risk due to toxicity of total arsenic in fly ash for the utilization scenario was found to be approximately 50% greater than the risk of toxicity in the complete storage scenario, thus rejecting the proposed hypothesis. The results of this risk assessment could be used in any future decision making by government and private agencies in situations regarding the storage and utilization of fly ash.

KEY WORDS: CANCER RISK ASSESSMENT / ARSENIC /
PULVERIZED FLY ASH (PFA) / LIGNITE POWER PLANT

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การประเมินความเสี่ยงต่อการเกิดโรคมะเร็งจากความเป็นพิษของสารหนูในเถ้าลอยเมื่อนำไปใช้
ประโยชน์หรือกองทิ้งของโรงไฟฟ้าแม่เมาะภาคเหนือของประเทศไทย (CANCER RISK
ASSESSMENT OF ARSENIC TOXICITY ON UTILIZATION OR STORAGE OF PULVERIZED
FLY ASH FROM MAE MOH LIGNITE POWER PLANT, NORTHERN THAILAND)

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บทคัดย่อ

งานวิจัยนี้ประเมินและเปรียบเทียบความเสี่ยงต่อการเกิดโรคมะเร็งจากความเป็นพิษของสารหนู
เมื่อนำเถ้าลอยจากโรงงานไฟฟ้าแม่เมาะไปใช้ประโยชน์หรือกองทิ้งโดยแบ่งออกเป็นสถานการณ์สมมุติ
3 สถานการณ์ได้แก่ สถานการณ์ปัจจุบัน(บางส่วนกองทิ้งและบางส่วนถูกนำไปใช้) สถานการณ์กองทิ้ง
เถ้าลอยทั้งหมดและสถานการณ์ใช้ประโยชน์เถ้าลอยทั้งหมดโดยแบ่งกลุ่มประชากรออกเป็น 3 กลุ่มได้แก่
กลุ่มประชากรปฏิบัติงานในโรงงานไฟฟ้าฯ กลุ่มผู้อยู่อาศัย และกลุ่มผู้ใช้ประโยชน์จากผลิตภัณฑ์ที่มีส่วน
ผสมของเถ้าลอย มีข้อสมมุติที่เหมาะสมเพื่อช่วยลดความซับซ้อนของขั้นตอนและกระบวนการประเมิน
ความเสี่ยงฯลง และนำแบบจำลองที่เหมาะสมมาใช้เพื่อประมาณค่าความเสี่ยงฯในแต่ละสถานการณ์
สมมุติ โดยเป็นไปตามมาตรฐานสากลขององค์กรป้องกันสิ่งแวดล้อมสหรัฐอเมริกา (U.S. EPA) เพื่อ
ทดสอบสมมุติฐานการวิจัย: ความเสี่ยงจากการใช้ประโยชน์เถ้าลอยมีค่าน้อยกว่าความเสี่ยงฯเมื่อนำเถ้า
ลอยไปกองทิ้ง การเก็บตัวอย่างในสถานที่ต่างๆประกอบด้วยตัวอย่างเถ้าลอย น้ำผิวดิน ดินและหญ้า ซึ่ง
สามารถเข้าสู่ร่างกายได้ 3 ทาง (Exposure Pathways) คือ ทางการกิน (Ingestion) ทางการหายใจ
(Inhalation) และการสัมผัสทางผิวหนัง (Dermal Contact) ผลการประเมินความเสี่ยงฯแสดงให้เห็นว่าค่า
ความเสี่ยงฯในทุกๆสถานการณ์สมมุติและทุกๆกลุ่มประชากรในการคิดแบบเฉลี่ย (Central Tendency
Exposure) และแบบค่าสูงสุดอย่างสมเหตุสมผล (Reasonable Maximum Exposure) อยู่ในเกณฑ์ที่ยอมรับ
ได้ตามมาตรฐานสากล ดังนั้นตามกฎหมายโรงไฟฟ้าฯจึงไม่จำเป็นต้องปรับปรุงดำเนินการหรือแก้ไขใดๆ
อย่างไรก็ตามปริมาณสารหนูซึ่งเป็นผลจากการดำเนินงานของโรงไฟฟ้าฯมีค่าสูงกว่าปริมาณที่เกิดขึ้นเอง
ตามธรรมชาติจึงควรส่งเสริมให้มีมาตรการเฝ้าระวัง ตรวจวัด ป้องกัน ตลอดจนบำบัดอย่างต่อเนื่อง
จากผลการวิจัยพบว่าความเสี่ยงฯ ที่เกิดจากการใช้ประโยชน์เถ้าลอยมีค่าสูงกว่าความเสี่ยงฯ ที่เกิดจากการ
กองทิ้งเถ้าลอยประมาณร้อยละ 50 แต่ยังคงอยู่ในเกณฑ์มาตรฐานและผลการวิจัยสามารถใช้เป็นเครื่องมือ
เพื่อการตัดสินใจและการจัดการที่เหมาะสมกับเถ้าลอยต่อไป

CONTENTS

	Page
ACKNOWLEDGEMENTS	iii
ABSTRACT	iv
LIST OF TABLES	viii
LIST OF FIGURES	xiii
CHAPTER	
I INTRODUCTION	1
1.1 Background of Study	1
1.2 Statement of Problem	3
1.3 Objectives of Study	4
1.4 Research Hypothesis	4
1.5 Scope of Study	4
1.6 Limitations	5
1.7 Organization of Research	5
1.8 Conceptual Framework	6
II LITERATURE REVIEW	7
2.1 Background Information of the Site	7
2.2 Utilization and Management of Fly Ash	22
2.3 Mae Moh Fly Ash	27
2.4 Compressive Strength and Leaching Tests	46
2.5 Arsenic and Related Health and Environmental Concerns	50
2.6 Hazardous Identification and Dose-Response Assessment	59
2.7 Human Health Risk Assessment	69
2.8 RISK*ASSISTANT	73
III MATERIALS AND METHODS	78
3.1 Materials	79
3.2 Methods	80
3.3 Process Analysis	88

CONTENTS (CONT.)

	Page
3.4 Result Implementation	89
3.5 Working Schedule	89
IV RESULTS	90
4.1 Introduction	90
4.2 Complete Exposure Pathways	90
4.3 Exposure Assessment	94
4.4 Quantification of Exposure	113
4.5 Calculation of Cancer Risks	118
4.6 Modeling of Risk Contribution from Fly Ash Particulates	120
4.7 Summary of Cancer Risks	125
4.8 Results of RISK*ASSISTANT	151
V DISCUSSIONS	152
5.1 Introduction	152
5.2 Evaluation of Methods	153
5.3 Evaluation of Results	156
5.4 Limitations and Uncertainty	161
VI CONCLUSIONS AND RECOMMENDATIONS	165
6.1 Conclusions	165
6.2 Recommendations	167
BIBIOGRAPHY	169
APPENDIX	185
BIOGRAPHY	239

LIST OF TABLES

Table	Page
1.1 Information on Plant Units 1 – 13	2
2.1 Climatological Data for 1971 – 2000 for Lampang Province	15
2.2 Climatological Data for 1971 – 2000 for Prae Province	16
2.3 Representative Fractions of the Overall Investigated Area	20
2.4 Physiographic and Soil Units of Mae Moh Lignite Mine	21
2.5 Natural Concentration of Arsenic in Human Bodies	51
3.1 Examples of Preliminary Data and Sources	81
3.2 Graphite Furnace Atomic Absorption Spectrophotometry Operating Conditions	83
3.3 Qualitative Expression of Risks	85
3.4 Casting Schedule of Compressive Strength Test at 90 days	87
3.5 Casting Schedule of Compressive Strength Test at 60 days	87
3.6 Casting Schedule of Compressive Strength Test at 28 days	87
3.7 Casting Schedule of Compressive Strength Test at 7 days	88
4.1 Chemical Properties of Mae Moh Fly Ash from 1990 – 1998	95
4.2 Mae Moh Fly Ash Properties in 1999	95
4.3 Summary of Description and Possible Complete Pathway for Occupational Populations	98
4.4 Residential Population Exposure Characteristics by Village	101
4.5 Information of Sampling Points for Determination of Arsenic Concentration	102
4.6 Background Arsenic Concentrations in the Mae Chang River	105
4.7 Average Total Arsenic Concentration (Submerged water and Crushed) for Different Percent Fly Ash in Mortars	108
4.8 Results of Compressive Strength Tests at 7 days	110
4.9 Results of Compressive Strength Tests at 28 days	110
4.10 Results of Compressive Strength Tests at 60 days	111
4.11 Results of Compressive Strength Tests at 90 days	111
4.12 Modeling and Extrapolation of Dust Concentration in Air	123
4.13 Summary of Cancer Risks for Occupational Population (Current Storage and Sale)	125
4.14 Summary of Cancer Risks for Residential Population of Hang Hung Village (Current Storage and Sale)	125
4.15 Summary of Cancer Risks for Residential Population of Mae Moh Station Village (Current Storage and Sale)	126

LIST OF TABLES (CONT.)

Table	Page
4.16 Summary of Cancer Risks for Residential Population of Mae Lu Village (Current Storage and Sale)	126
4.17 Summary of Cancer Risks for Residential Population of Don Mun Village (Current Storage and Sale)	126
4.18 Summary of Cancer Risks for Residential Population of Hua Sua Village (Current Storage and Sale)	126
4.19 Summary of Cancer Risks for Residential Population of Sop Rai Village (Current Storage and Sale)	127
4.20 Summary of Cancer Risks for Residential Population of Ban Kom Village (Current Storage and Sale)	127
4.21 Summary of Cancer Risks for Residential Population of Ban Mai1 Village (Current Storage and Sale)	127
4.22 Summary of Cancer Risks for Residential Population of Ban Mai8 Village (Current Storage and Sale)	127
4.23 Summary of Cancer Risks for Residential Population of Pong Pa Pao Village (Current Storage and Sale)	128
4.24 Summary of Cancer Risks for Residential Population of Sop Po Village (Current Storage and Sale)	128
4.25 Summary of Cancer Risks for Residential Population of Ban Luk Village (Current Storage and Sale)	128
4.26 Summary of Cancer Risks for Residential Population of Ban Luk Tai Village (Current Storage and Sale)	128
4.27 Summary of Cancer Risks for Residential Population of Nam Thong Village (Current Storage and Sale)	129
4.28 Summary of Cancer Risks for Residential Population of Nong Thoi Village (Current Storage and Sale)	129
4.29 Summary of Cancer Risks for Residential Population of Ban Hom Village (Current Storage and Sale)	129
4.30 Summary of Cancer Risks for Residential Population of Na Kwao Village (Current Storage and Sale)	129
4.31 Summary of Cancer Risks for Residential Population of Na Khot Village (Current Storage and Sale)	130
4.32 Summary of Cancer Risks for Residential Population of Pa Tan Nua Village (Current Storage and Sale)	130
4.33 Summary of Cancer Risks for Residential Population of Pa Tan Tai Village (Current Storage and Sale)	130
4.34 Summary of Cancer Risks for Residential Population of Sop Tha Village (Current Storage and Sale)	130
4.35 Summary of Cancer Risks for Residential Population of Ban Nong4/9 Villages (Current Storage and Sale)	131
4.36 Summary of Cancer Risks for Residential Population of Ban To Village (Current Storage and Sale)	131

LIST OF TABLES (CONT.)

Table	Page
4.37 Summary of Cancer Risks for Residential Population of Ban Pao Village (Current Storage and Sale)	131
4.38 Summary of Cancer Risks for Residential Population of Wang Phrao Village (Current Storage and Sale)	131
4.39 Summary of Cancer Risks for Residential Population of Sop Chang Village (Current Storage and Sale)	132
4.40 Summary of Cancer Risks for Utilization Population (Current Storage and Sale)	132
4.41 Summary of Cancer Risks for Occupational Population (Complete Storage)	133
4.42 Summary of Cancer Risks for Residential Population of Hang Hung Village (Complete Storage)	134
4.43 Summary of Cancer Risks for Residential Population of Mae Moh Station Village (Complete Storage)	134
4.44 Summary of Cancer Risks for Residential Population of Mae Lu Village (Complete Storage)	134
4.45 Summary of Cancer Risks for Residential Population of Don Mun Village (Complete Storage)	135
4.46 Summary of Cancer Risks for Residential Population of Hua Sua Village (Complete Storage)	135
4.47 Summary of Cancer Risks for Residential Population of Sop Rai Village (Complete Storage)	135
4.48 Summary of Cancer Risks for Residential Population of Ban Kom Village (Complete Storage)	135
4.49 Summary of Cancer Risks for Residential Population of Ban Mai1 Village (Complete Storage)	136
4.50 Summary of Cancer Risks for Residential Population of Ban Mai8 Village (Complete Storage)	136
4.51 Summary of Cancer Risks for Residential Population of Pong Pa Pao Village (Complete Storage)	136
4.52 Summary of Cancer Risks for Residential Population of Sop Po Village (Complete Storage)	136
4.53 Summary of Cancer Risks for Residential Population of Ban Luk Village (Complete Storage)	137
4.54 Summary of Cancer Risks for Residential Population of Ban Luk Tai Village (Complete Storage)	137
4.55 Summary of Cancer Risks for Residential Population of Nam Thong Village (Complete Storage)	137
4.56 Summary of Cancer Risks for Residential Population of Nong Thoi Village (Complete Storage)	137
4.57 Summary of Cancer Risks for Residential Population of Ban Hom Village (Complete Storage)	138
4.58 Summary of Cancer Risks for Residential Population of Na Kwao Village (Complete Storage)	138

LIST OF TABLES (CONT.)

Table	Page
4.59 Summary of Cancer Risks for Residential Population of Na Khot Village (Complete Storage)	138
4.60 Summary of Cancer Risks for Residential Population of Pa Tan Nua Village (Complete Storage)	138
4.61 Summary of Cancer Risks for Residential Population of Pa Tan Tai Village (Complete Storage)	139
4.62 Summary of Cancer Risks for Residential Population of Sop Tha Village (Complete Storage)	139
4.63 Summary of Cancer Risks for Residential Population of Ban Nong4/9 Village (Complete Storage)	139
4.64 Summary of Cancer Risks for Residential Population of Ban To Village (Complete Storage)	139
4.65 Summary of Cancer Risks for Residential Population of Ban Pao Village (Complete Storage)	140
4.66 Summary of Cancer Risks for Residential Population of Wang Phrao Village (Complete Storage)	140
4.67 Summary of Cancer Risks for Residential Population of Sop Chang Village (Complete Storage)	140
4.68 Summary of Cancer Risks for Occupational Population (Complete Sale)	141
4.69 Summary of Cancer Risks for Residential Population of Hang Hung Village (Complete Sale)	142
4.70 Summary of Cancer Risks for Residential Population of Mae Moh Station Village (Complete Sale)	142
4.71 Summary of Cancer Risks for Residential Population of Mae Lu Village (Complete Sale)	142
4.72 Summary of Cancer Risks for Residential Population of Don Mun Village (Complete Sale)	142
4.73 Summary of Cancer Risks for Residential Population of Hua Sua Village (Complete Sale)	143
4.74 Summary of Cancer Risks for Residential Population of Sop Rai Village (Complete Sale)	143
4.75 Summary of Cancer Risks for Residential Population of Ban Kom Village (Complete Sale)	143
4.76 Summary of Cancer Risks for Residential Population of Ban Mai1 Village (Complete Sale)	143
4.77 Summary of Cancer Risks for Residential Population of Ban Mai8 Village (Complete Sale)	144
4.78 Summary of Cancer Risks for Residential Population of Pong Pa Pao Village (Complete Sale)	144
4.79 Summary of Cancer Risks for Residential Population of Sop Po Village (Complete Sale)	144
4.80 Summary of Cancer Risks for Residential Population of Ban Luk Village (Complete Sale)	144

LIST OF TABLES (CONT.)

Table	Page
4.81 Summary of Cancer Risks for Residential Population of Ban Luk Tai Village (Complete Sale)	145
4.82 Summary of Cancer Risks for Residential Population of Nam Thong Village (Complete Sale)	145
4.83 Summary of Cancer Risks for Residential Population of Nong Thoi Village (Complete Sale)	145
4.84 Summary of Cancer Risks for Residential Population of Ban Hom Village (Complete Sale)	145
4.85 Summary of Cancer Risks for Residential Population of Na Kwao Village (Complete Sale)	146
4.86 Summary of Cancer Risks for Residential Population of Na Khot Village (Complete Sale)	146
4.87 Summary of Cancer Risks for Residential Population of Pa Tan Nua Village (Complete Sale)	146
4.88 Summary of Cancer Risks for Residential Population of Pa Tan Tai Village (Complete Sale)	146
4.89 Summary of Cancer Risks for Residential Population of Sop Tha Village (Complete Sale)	147
4.90 Summary of Cancer Risks for Residential Population of Ban Nong4/9 Village (Complete Sale)	147
4.91 Summary of Cancer Risks for Residential Population of Ban To Village (Complete Sale)	147
4.92 Summary of Cancer Risks for Residential Population of Ban Pao Village (Complete Sale)	147
4.93 Summary of Cancer Risks for Residential Population of Wang Phrao Village (Complete Sale)	148
4.94 Summary of Cancer Risks for Residential Population of Sop Chang Village (Complete Sale)	148
4.95 Summary of Cancer Risks for Utilization Population (Complete Sale)	149
4.96 Percent Contribution of Risk by Pathways (Occupational Population)	150
4.97 Percent Contribution of Risk by Pathways (Residential Population)	150
4.98 Percent Contribution of Risk by Pathways (Utilization Population)	150
4.99 Results of Cancer Risks by Manual Evaluation and RISK*ASSISTANT	151

LIST OF FIGURES

Figure	Page
1.1 Relationship between Risk Assessment and Risk Management	4
2.1 Topographic Map of Mae Moh Basin	8
2.2 Typical Geological Cross Section of Mae Moh Basin	9
2.3 Geological Map of Mae Moh Area	10
2.4 Typical Mae Moh Coal Zone	12
2.5 Schematic Model of Mae Moh Basin	12
2.6 Faulting Structures of Mae Moh Basin	13
2.7 Average Monthly Rainfall at Mae Moh Station	14
2.8 Average Monthly Temperature at Mae Moh Station	17
2.9 Hythergraph of Mae Moh Mining Area	18
2.10 Fly Ash	29
2.11 Fly Ash at the Storage Site	29
2.12 Processes at Ready Mixed Concrete Plant	40
4.1 Complete Exposure Pathways of Human Health Risk Assessment	90
4.2 Exposure Pathways for Complete Storage of Fly Ash	92
4.3 Exposure Pathways for Utilizing Fly Ash as Construction Materials	93
4.4 Approximate Locations of Treatment Ponds, Schools, and Villages downstream of Plant, along the Mae Chang River	102
4.5 Plot of Total Arsenic Concentration by Village	104
4.6 Arsenic Concentration along the Mae Chang River	104
4.7 Plot of Arsenic Concentration of Background Points	105
4.8 Plot of Leaching Test Results at Different Percentages of Fly Ash in Mortars	109
4.9 Plot of Compressive Strength and Percent Fly Ash	112
4.10 Relationship of Dust Concentration in Air and Fly Ash Sale Amount for Plant Unit 8	121
4.11 Relationship of Dust Concentration in Air and Fly Ash Sale Amount for Plant Unit 9	121
4.12 Relationship of Dust Concentration in Air and Fly Ash Sale Amount for Plant Unit 11	122
4.13 Relationship of Dust Concentration in Air and Fly Ash Sale Amount for Plant Unit 13	122

CHAPTER I

INTRODUCTION

1.1 Background of Study

Since its first operation in 1964, Mae Moh Lignite Power Plant, Lampang province of Thailand, has been generating a growing amount of electricity due to the in demand as a result of industry expansion, and economic and population growth. (Kunawanakij, 1997). Currently, it is operating with 10 units of machines, yielding the total of 2,400 mega-watts of electricity, approximately 10 – 15 % of national production (EGAT, 2003a and Jungkasemchokchai, 2001). Such higher production requires larger input, which, among others, is lignite coal. Presently, each day approximately 45,000 tons of lignite coal are dug up at lignite mine and transported to the manufactures to generate electricity to support the North, Northeast and Central regions of Thailand (EGAT, 2003b).

Fly ash, a major by-product from Mae Moh Power Plant, receives substantial consideration from the industry and researchers due to its large amount of production, its potentially desirable characteristics for reutilization, and its possible contamination to the environment.

The fly ash sale amount and price have been increasing in the past years, as a result of reconstruction of the plant infrastructure so that trucks can be loaded with fly ash from silos, however the remaining portion has to be continuously transported through belt conveyors to the storage site, several kilometers away, with no further treatment. The current storage site is a limestone valley covering an area of many square kilometers, with an estimated existing 50 million tons of fly ash (Table 1.1; Ponlit, 2003; and site survey).

Table 1.1: Information on Plant Units 1 - 13

Unit	Power (MW)	Lignite Consumption Rate/Yr (MT)	Began Operation
1	75	Total	1978
2	75	1.5	1978
3	75		1981
4	150	1.0	1984
5	150	1.0	1984
6	150	1.0	1985
7	150	1.0	1985
8	300	2.0	1989
9	300	2.0	1990
10	300	2.0	1991
11	300	2.0	1991
12	300	2.0	1995
13	300	2.0	1995

Although many types of utilization have been done and investigated, practically the most quantity of fly ash utilization around the world, including Thailand, has been related with cement and concrete application or in other words construction materials. This type of fly ash utilization contributes to possible environmental, economic, and technological benefits in the concept of the United States sustainability initiatives' 3E's: economic, engineering, and environment (Holtz and Eighmy, 2001). The 'by-product' stabilization/ solidification process of fly ash is proven beneficial to the environment due to dramatically lower leachate concentrations of hazardous materials. While, in many occasions, fly ash concretes provide economic advantages (ACI 232.2R-96).

However, in Thailand, recently, there has been a vast disagreement about the principle of fly ash utilization. The newly proposed standards for fly ash utilization as construction materials by the Thai Industrial Standard Institute, supported by the Engineering Institute of Thailand, were opposed by the Thai Association of

Construction Industry. There are a large number of pro-utilizers of fly ash due to reasons mentioned above, while others are worried about hazardous effects from fly ash-incorporating cement, mortar or concrete, which become much closer to interacting with people in many types of possible application, although lower in leachate concentrations.

1.2 Statement of Problem

Continuously, much effort in terms of money and energy is involved with transportation of many thousand tons of untreated fly ash to be disposed off on top of the accumulated substantially large volume of ash already existing at the disposal site. Fly ash at the storage site can potentially pose immense environmental problems to the environment and humans due to three main reasons. The first reason is that fly ash itself has high potential hazard due to characteristics of its constituents. The second reason lies on its considerable amount of existing and high volume of daily production. Lastly, fly ash, both trapped, collected and treated at the plants and at the storage site may not be properly controlled and it is possible that it will find pathways to cause adverse effects to humans living downstream.

Of all leachable elements from fly ash, arsenic is considered the potentially most serious to human health. Arsenic has been classified by the U.S. EPA as Class A human carcinogen and the top of most hazardous substances list, based on 'sufficient evidence' from human data after arsenic's carcinogenic role was first noted over a hundred years ago. (EPA, 2000) An EPA report (2000) also stated that *'epidemiological studies...clearly show associations of arsenic with several internal cancers at exposure concentrations of several hundred micrograms per liter of drinking water.'*

None of the studies, so far, has been done to investigate comprehensive human health assessment caused by fly ash at storage site of Mae Moh Power Plant. Nor has any study ever investigated human health caused by utilization of fly ash as construction materials. In order to lessen the degree of conflicts among professionals and practitioners, and to be able to confidently utilize fly ash, or to find appropriate remediation or treatment for possible risk, comparative assessment of both

circumstances has to be evaluated. Proper decision making in terms of risk management will be possible. (Figure 1.1)

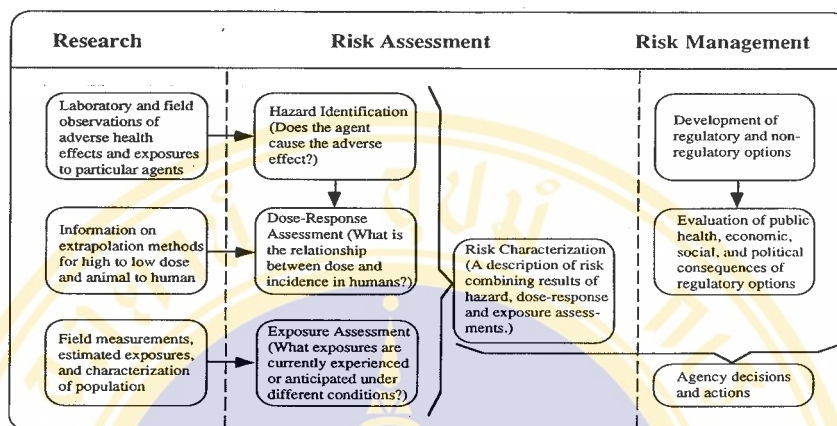


Figure 1.1: Relationship between Risk Assessment and Risk Management

1.3 Objectives of Study

- 1) To investigate and assess human risk due to arsenic for the storage of Mae Moh fly ash.
- 2) To investigate and assess human health risk due to arsenic for utilizing fly ash as construction materials.
- 3) To compare risks from 1) and 2) to support national and local decision making regarding fly ash utilization.

1.4 Research Hypothesis

Overall human health risk due to toxicity of total arsenic in fly ash when fly ash is utilized as construction materials is less than that resulting from toxicity due to storage of fly ash.

1.5 Scope of Study

Area of study will contain the territory of Mae Moh Electricity Generating Plant, Amphur Mae Moh, Lampang Province, approximately 600 kilometers north of Bangkok, covering an area of approximately 130,000 rais (52,000 acres).

The surrounding area of fly ash storage site will also be investigated. Other area along possible pathways, such as rivers, is an area of concern that needs investigation.

Toxic element of interest for human health risk assessment is arsenic. The study will focus on total arsenic. Total arsenic will be measured. Speciation, arsenate (+5) and arsenite (+3), will be approximated, when appropriate.

Time frame of study constitutes of several phases: data collection and sampling, experimental works, and assessment and analytical phase. Complete processes will take approximately 15 months.

Laboratory works are primarily based on two types of experimental testings: compressive strength test by Universal Testing Machine (UTM) at Chulachomkiao Royal Military Academy, and total arsenic concentration measurement by Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS) at the Faculty of Science, Mahidol University. Compressive strength samples include 100 cubes of fly ash-cement mortars, and the leaching test samples consist of 60 leachate water samples from fly ash-cement mortars. While, total arsenic concentration of fly ash, soils, surface water, and grasses at different location, will be determined.

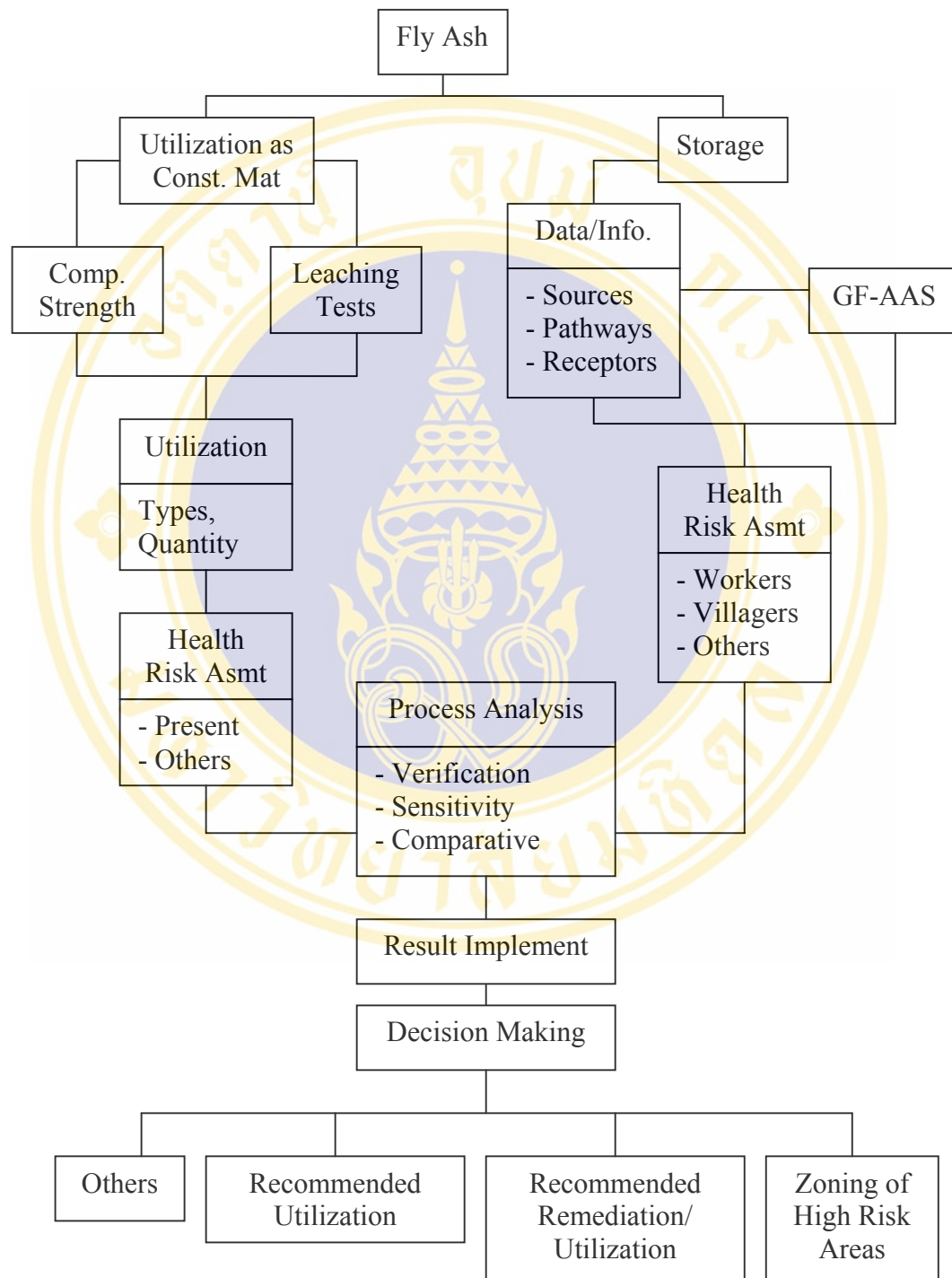
1.6 Limitations

Due to inadequacy of previous studies at the area of study and in Thailand, assessment of human health risk must rely on toxicity information based on other locations of the world. Best educated estimates will be input in an evaluation process.

1.7 Organization of Thesis

The thesis is organized into the following Chapters: Chapter 1, Introduction; Chapter 2, Literature Review; Chapter 3; Materials and Methods; Chapter 4, Results; Chapter 5, Discussions; Chapter 6, Conclusions and Recommendations.

1.8 Conceptual Framework



CHAPTER II

LITERATURE REVIEW

2.1 Background Information of the Site

2.1.1 Physiographical/Geological Setting and Lignite Deposit

2.1.1.1 Mae Moh Site Physiographical and Geological Setting

The Mae Moh basin covers an area of approximately 150 square kilometers. The north boundary is surrounded by Kew-lom quartzites mountains, while the east and west boundaries are bounded by limestone Chang mountains and mudrock Luang mountains, respectively. The mountain range on the western side has the crest elevation of 700 meters above mean sea level. The southern boundary is bounded by the basalt-flows over limestone Pha Hob mountains.

In general, the topography of the basin can be classified as flat and low lying terrain with the altitude of ground surface throughout the basin ranges between 300 to 350 meters MSL. However, slightly rolling topographic expression is found in places along the flat lying ground of the basin as compared with those of rugged and mountainous surrounding area. The basin itself is formed in the north-south direction with a length of 17 kilometers and width of 9 kilometers. Topographic map of the Mae Moh basin, including operating area is shown in Figure 2.1.

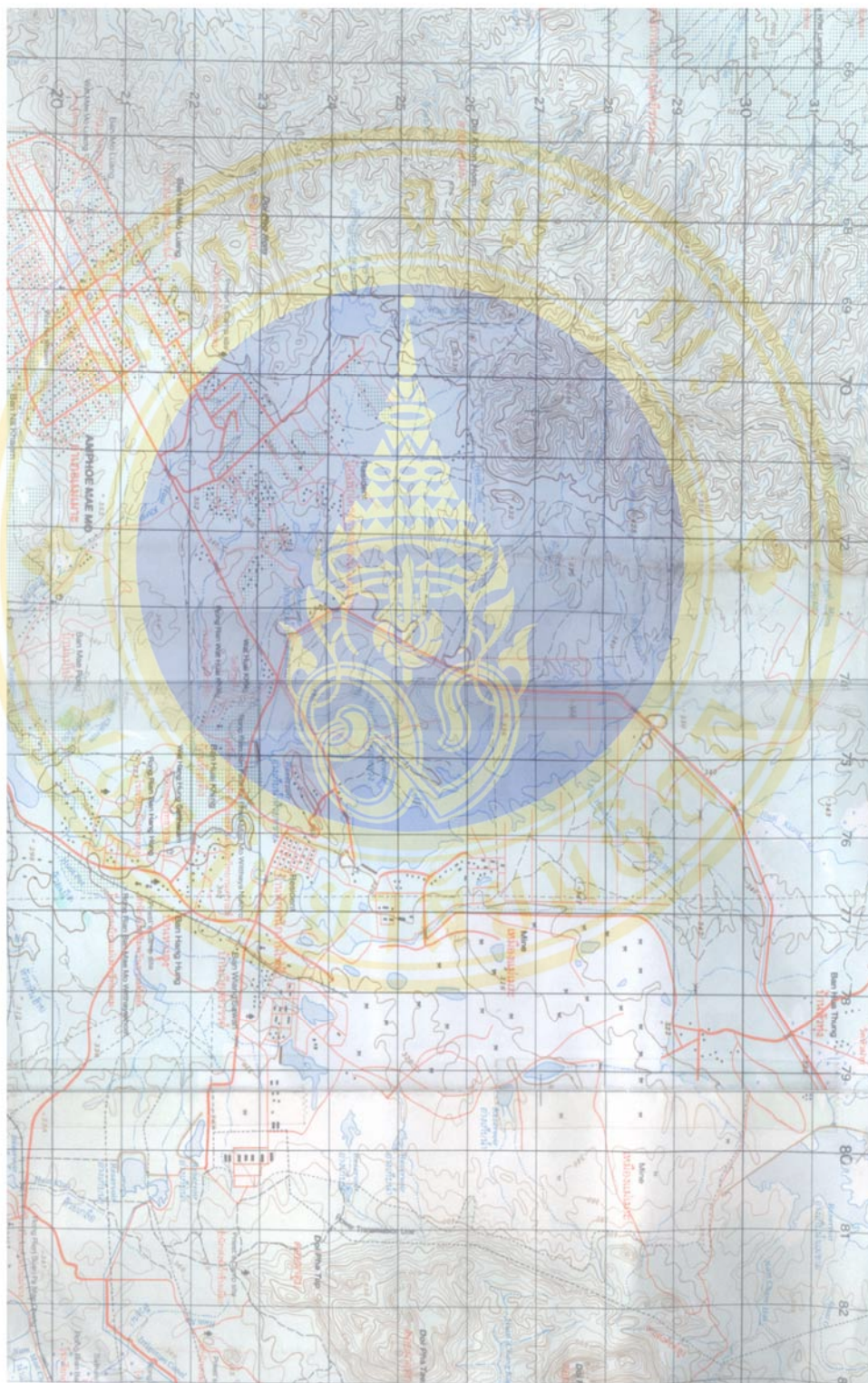


Figure 2.1: Topographic Map of Mae Moh Area

The basin was formed during the Tertiary period on the presumably limestone basement. The sediments infilling the basin are mainly semi-consolidated in nature with diversified lithology. Within the uppermost 10 meters of the basin, sediments of fluvial origin, namely clay, lateritic soils and terrace gravel are predominant. These sediments are unconsolidated due to their recent ages. Below the 10 meter depth, sediments are mudstone and the lignite deposits, occurring in 2 or 3 seams, have an average thickness of 15 – 20 meters, interbedded with claystones or mudstones. The depth from the ground surface to lignite deposits varies from very shallow along the marginal area of the basin to relatively deeper in the central part of the basin (up to 300 meters). Several tectonic faultings have been reported along the margin of the basin and apparently displacing lignite seams to some degree. Figure 2.2 shows the typical geological cross section of the Mae Moh basin, while Figure 2.3 displays the geological map of the area.

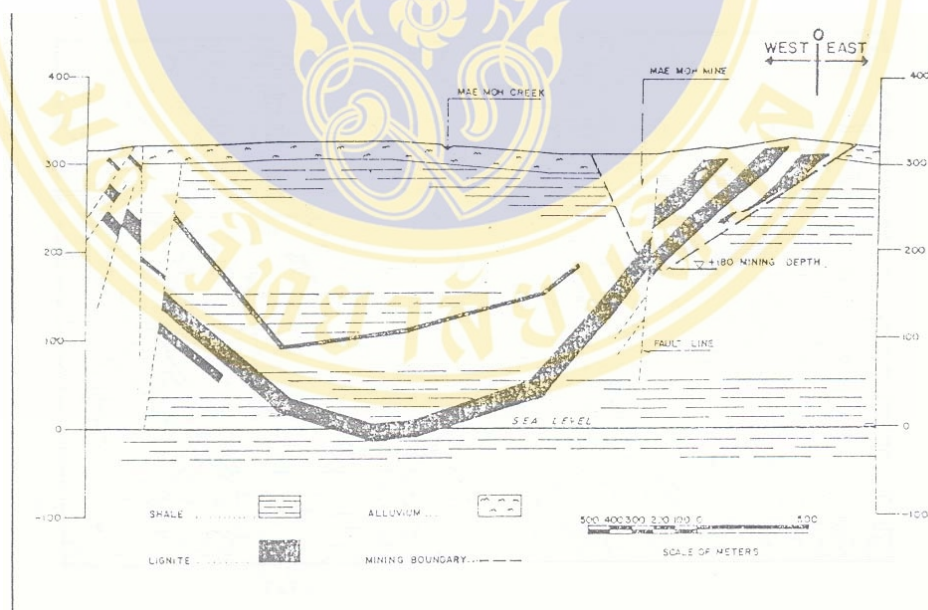


Figure 2.2: Typical Geological Cross Section of Mae Moh Basin

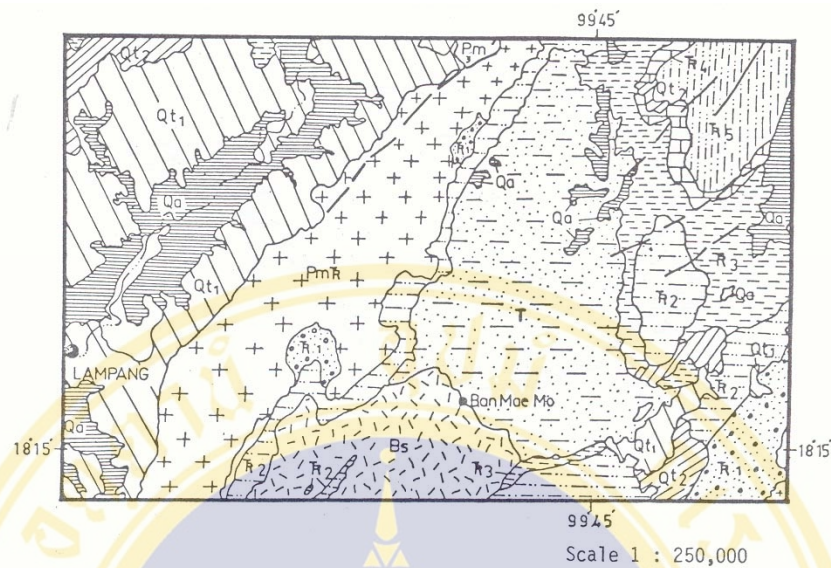


Figure 2.3: Geological Map of Mae Moh Area

Explanation to Figure 2.3

Q1	River gravel, sand, clay and mud
Qt1	Lower terraces, gravel, sand silt, clay
Qt2	Higher terraces, gravel, sand silt, clay (Mae Taeng Group)
T	Fresh-water sandstone, shale, carbonaceous shale, limestone, viviparus beds, lignite (Mae Moh Group)
T5	Reddish-brown sandstone, shale, conglomerate, greenish-grey siltstone, shale, sandstone (Pha Daeng Formation, Lampang Group)
T4	Limestone, limestone conglomerate; medium grey to pinkish-grey with fossils of gastropod, brachiopods (Doi Chang Formation, Lampang Group)
T3	Greenish-grey shale, sandstone, tuffaceous sandstone, laminated shale, conglomerate, with fossils of Halobia, Daonella, Posidonia, Trachycers, Paratrachyceras, Joannites, etc. (Hong Hoi Formation, Lampang Group)
T2	Limestone, massive or banded, dark grey to medium grey; shale, sandstone, calcareous, grey to grayish-brown, well stratified, with fossils of brachiopods, Claraia, Halobia, Daonella, Posidonia, Ammonites, (Pha Kan Formation, Lampang Group)
T1	Basal conglomerate; reddish-brown sandstone, shale, agglomerate, tuff, (Pha Thai Formation, Lampang Group)
Pm3	Shale, calcareous shale, carbonaceous shale, tuffaceous shale and sandstone, laminated shale with fossils of Dielasma, Leptodus, Orthotichia, Echinochus, Neospirifera, Schizophora, Aviculopecten, etc. (Huai Thak Formation Ratchaburi Group),
Bs	Basalt; vesicular, Amygdaloidal

As geologically explained in the figures, coals exist in bed or layers along with other sedimentary rocks, mostly shell and sandstones. The coal particle consists of fossil wood, bark, leaves, roots, and other parts of land plants, which are chemically altered. Unlike most other sediments, coal was not eroded, transported and deposited, rather it was accumulated where plants grew, including coal beds at fossil tree stumps rooted in place in underlying shale. Although coal is interbedded with inorganic sediments, it is not usually mixed with them. The places of coal accumulation are swamps, which attributed to a complete physical and chemical gradation from coal to peat.

Coal is formed in layers or seams. Each seam is flat, lens-shape body, which corresponds to area of swamp where it is originally accumulated. While most seams are 2 – 10 feet thick, some could be as thick as 100 feet.

Chemically, peat and lignite may compose of several elements, which are concentrated during decay period of reducing condition. Under reduction, many elements can occur. These include arsenic, boron, bismuth, germanium, nickel, cobalt, cadmium, lead and others and they may be converted to unstable forms and intermixed with the decayed inorganic to form peat and lignite. All of these depend on local geochemical condition as well as plants condition (Institute of Environmental Research, Chulalongkorn University, 1981; EGAT, 1979; EGAT, 1993).

2.1.1.2 Mae Moh Lignite Deposit

Total geological lignite reserve of Mae Moh basin is approximately 1,500 million tons, and found in three seams, known as J, K, and Q. The J seam is existing only in the northern part in 6 thin seams, while K and Q seams are found throughout the basin with 20 – 30 meters of thickness. The deposit had many faulting structures throughout the basin. Figure 2.4, Figure 2.5, and Figure 2.6 illustrate typical coal zone, schematic model and faulting structures of Mae Moh basin (Institute of Environmental Research, Chulalongkorn University, 1981; EGAT, 1979; EGAT, 1993).

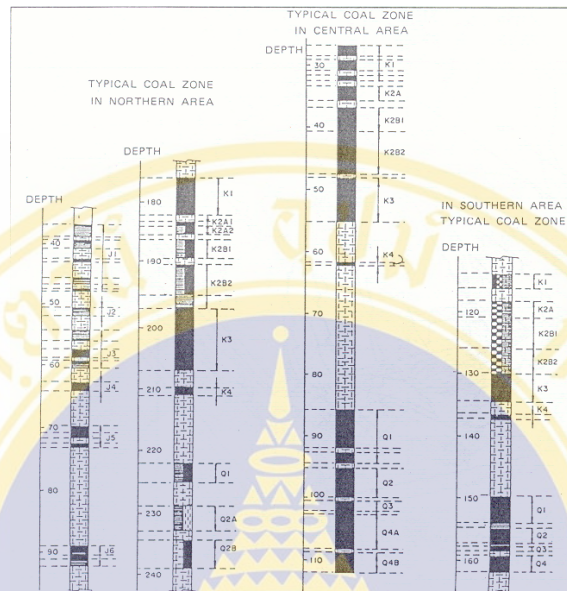


Figure 2.4: Typical Mae Moh Coal Zone

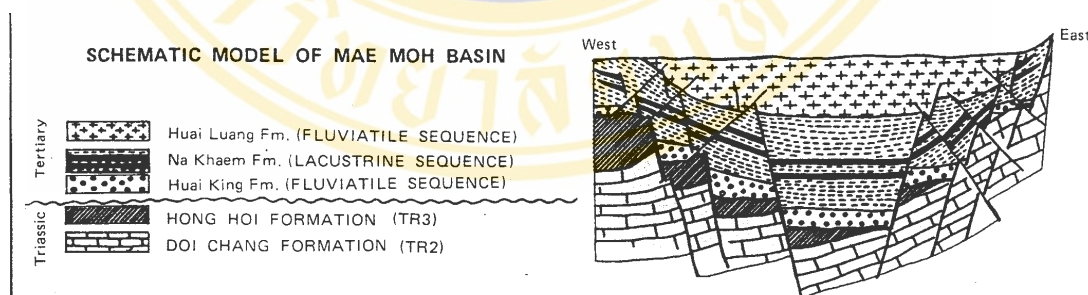


Figure 2.5: Schematic Model of Mae Moh Basin



Figure 2.6: Faulting Structures of Mae Moh Basin

2.1.2 Climate

The climatic environment of Mae Moh basin can be defined as the typical northern Thailand climate. It is located in the monsoon zone, which is influenced yearly mainly by 2 monsoons, namely the southwest and northeast, and secondarily by cyclonic storm and intertropical fronts.

During May and October, the air mass moves from Indian Ocean and brings moisture creating rainy season. Cyclonic storms from the Pacific Ocean cause intense precipitation in the region. Heavy rainfall occurs when cool air from the north encounters the southwest monsoon. Eighty five to ninety percent of annual rainfall is caused by the southwest monsoon. The dry season occurs during mid-October and mid-February when cool air mass from the polar region moves south across Siberia and mainland China creating cool dry weather with no rain. During mid-February and mid-May, the polar air mass is modified to tropical heat and moves into the basin creating a hot and dry weather over the region (Institute of Environmental Research, Chulalongkorn University, 1981).

2.1.3 Rainfall

There are three types of rainfall; orographic, convective, and cyclonic. During rainy season, orographic cyclonic prevails, while the local convective rains of high intensity occur during the summer. Figure 2.7 illustrates the average monthly rainfall at Mae Moh station. Table 2.1 and Table 2.2 show the climatological data for the period of 1971 – 2000 for Lampang and Prae provinces, respectively.

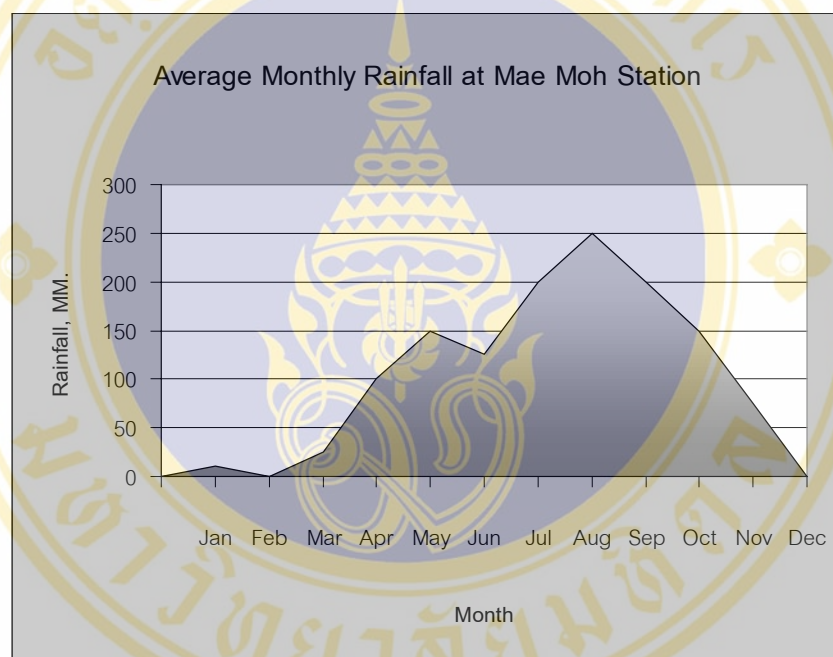


Figure 2.7: Average Monthly Rainfall at Mae Moh Station

While, the average monthly rainfall ranges from 0.6 to 251.2 mm. The minimum rainfall occurs during February because the dry-cool air masses move in the region from the pole. The maximum rainfall occurs in August due to the southwest monsoon from the Indian Ocean (Institute of Environmental Research, Chulalongkorn University, 1981).

Table 2.1: Climatological Data for 1971 – 2000 for Lampang Province

CLIMATOLOGICAL DATA FOR THE PERIOD 1971-2000													
Station	LAMPANG											Elevation of station above MSL	241 Meters
Index station	48328											Height of barometer above MSL	242 Meters
Latitude	18 17 N											Height of thermometer above ground	1.20 Meters
Longitude	99 31 E											Height of wind vane above ground	11.80 Meters
												Height of rain gauge	0.80 Meters
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Pressure (Hectopascal)													
Mean	1013.66	1011.36	1009.00	1007.11	1006.13	1004.89	1004.97	1005.32	1007.78	1010.79	1013.53	1015.32	1009.16
Ext. max.	1026.59	1023.52	1025.68	1019.68	1015.22	1012.59	1012.61	1012.78	1016.12	1020.62	1025.16	1027.09	1027.09
Ext. min.	1002.93	1000.23	998.36	996.36	997.20	995.92	990.57	996.14	998.64	1000.86	1002.95	1004.48	990.57
Mean daily range	6.40	6.99	7.12	6.83	5.76	4.63	4.38	4.62	5.23	5.46	5.55	6.11	5.76
Temperature (Celsius)													
Mean	21.5	23.9	27.4	29.5	28.7	28.1	27.6	27.2	26.8	25.9	23.7	21.0	25.9
Mean max.	30.7	33.7	36.6	37.8	35.3	33.7	32.9	32.5	32.3	31.8	30.6	29.4	33.1
Mean min.	14.4	15.9	19.6	22.9	24.0	24.2	24.0	23.7	23.3	22.1	18.8	14.8	20.6
Ext. max.	36.6	40.0	42.5	43.5	43.2	41.1	38.6	37.6	36.2	36.6	36.0	35.7	43.5
Ext. min.	3.9	8.7	11.5	17.6	19.5	21.4	21.0	21.2	19.6	12.7	7.1	3.7	3.7
Relative Humidity (%)													
Mean	72	63	58	61	73	77	78	81	84	83	80	76	74
Mean max.	94	89	85	85	91	91	92	94	96	96	95	95	92
Mean min.	40	31	30	35	50	57	59	62	64	61	54	46	49
Ext. min.	15	12	10	12	17	32	36	38	41	36	29	21	10
Dew Point (Celsius)													
Mean	15.3	15.3	17.0	20.0	22.6	23.2	23.1	23.4	23.6	22.6	19.6	15.9	20.1
Evaporation (mm.)													
Mean	89.8	112.1	159.3	179.2	164.2	136.7	127.2	117.5	107.7	100.1	87.0	81.3	1462.1
Cloudiness (0-10)													
Mean	2.4	2.1	2.4	4.1	6.3	7.8	8.3	8.4	7.5	6.1	4.5	3.2	5.3
Sunshine Duration (hr.)													
NO OBSERVATION													
Visibility (km.)													
0700 L.S.T.	3.6	3.3	3.8	5.9	9.5	11.1	11.1	10.6	8.1	5.8	4.8	4.4	6.8
Mean	6.5	5.4	5.4	7.6	11.3	12.4	12.1	11.8	10.8	9.7	9.0	8.0	9.2
Wind (Knots)													
Mean wind speed	.6	.9	1.2	1.5	1.4	1.6	1.6	1.2	.7	.5	.5	.5	-
Prevailing wind	S	S	S	S	S	S	S	S	S	S	NE	NE	-
Max. wind speed	24	54	99	57	46	39	44	43	38	32	99	20	99
Rainfall (mm.)													
Mean	5.6	7.6	20.5	65.1	148.5	114.7	146.0	193.4	210.3	106.4	34.3	7.6	1060.0
Mean rainy day	1.0	1.4	2.4	6.6	14.7	14.4	17.6	18.7	17.4	11.9	3.9	1.1	111.1
Daily maximum	35.9	32.9	59.7	140.0	68.9	102.2	97.1	78.7	109.9	71.7	77.9	54.8	140.0
Number of days with													
Haze	25.5	26.9	28.6	21.3	2.5	.1	.0	.0	.8	3.2	7.0	14.3	130.2
Fog	4.7	2.1	1.1	.1	.1	.0	.0	.1	1.7	5.1	7.8	7.7	30.5
Hail	.0	.1	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.2
Thunderstorm	.2	.8	3.2	8.4	15.1	8.3	7.4	10.0	14.3	8.0	1.8	.1	77.6
Squall	.0	.0	.1	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1

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2-Apr-01

Table 2.2: Climatological Data for 1971 – 2000 for Prae Province

CLIMATOLOGICAL DATA FOR THE PERIOD 1971-2000													
ation PHRAE												Elevation of station above MSL	161 Meters
dex station 48330												Height of barometer above MSL	162 Meters
titude 18 10 N												Height of thermometer above ground	1.25 Meters
nitude 100 10 E												Height of wind vane above ground	15.00 Meters
												Height of raingauge	0.85 Meters
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
essure (Hectopascal)													
an	1013.48	1011.23	1008.99	1007.14	1006.13	1004.96	1005.05	1005.36	1007.68	1010.63	1013.32	1015.06	1009.09
t. max.	1026.12	1023.51	1024.62	1019.82	1014.22	1012.52	1013.14	1012.84	1016.02	1020.34	1024.63	1026.88	1026.88
t. min.	1003.08	1000.36	998.94	996.17	997.37	995.05	996.74	996.21	998.04	1000.88	1003.72	1003.71	995.05
an daily range	6.16	6.58	6.67	6.57	5.58	4.51	4.29	4.47	5.10	5.30	5.44	5.87	5.55
emperature (Celsius)													
an	21.9	24.1	27.6	29.8	28.9	28.1	27.6	27.2	27.0	26.3	24.2	21.6	26.2
an max.	30.9	33.4	36.1	37.3	35.2	33.5	32.5	32.1	32.2	32.0	31.0	29.8	33.0
an min.	15.1	16.9	20.7	23.9	24.4	24.4	24.1	24.0	23.8	22.6	19.3	15.4	21.2
t. max.	35.6	38.5	41.7	43.6	42.8	39.7	39.2	37.5	35.8	36.5	35.4	34.9	43.6
t. min.	4.6	9.4	9.9	18.1	16.1	20.0	20.0	20.5	18.5	14.5	8.8	5.0	4.6
lative Humidity (%)													
an	74	67	61	63	74	79	81	83	84	83	79	76	75
an max.	95	91	84	83	90	92	93	94	95	96	96	95	92
an min.	43	38	36	40	53	60	64	67	66	62	54	46	52
t. min.	16	13	13	16	21	33	33	38	44	32	28	25	13
w Point (Celsius)													
an	16.3	16.8	18.6	21.2	23.3	23.8	23.7	23.9	24.0	23.0	20.0	16.5	20.9
aporation (mm.)													
an-Jan	106.7	123.5	182.1	200.8	186.3	153.1	144.4	133.2	126.1	120.9	105.0	100.2	1682.3
oudiness (0-10)													
an	2.3	2.1	2.2	3.5	6.3	7.6	8.2	8.4	7.5	5.7	4.0	2.8	5.1
inshine Duration (hr.)													
						</							

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Climatology division
Meteorological department
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2.1.4 Temperature

The temperature of the basin exhibits large daily variation with the maximum temperature of 40.9 °C in April and lowest 6.8 °C in January. The average monthly temperature is rather high with small variation between months. The maximum mean monthly temperature is 37.6 °C. The minimum average temperature recorded in January is 12.1 °C. Figure 2.8 shows recorded temperature at Mae Moh station, while Figure 2.9 shows hythergraph of Mae Moh mining area (Institute of Environmental Research, Chulalongkorn University, 1981).

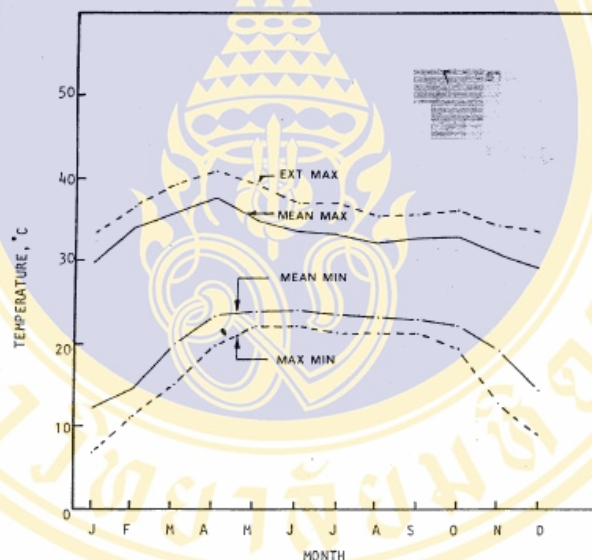


Figure 2.8: Average Monthly Temperature at Mae Moh Station

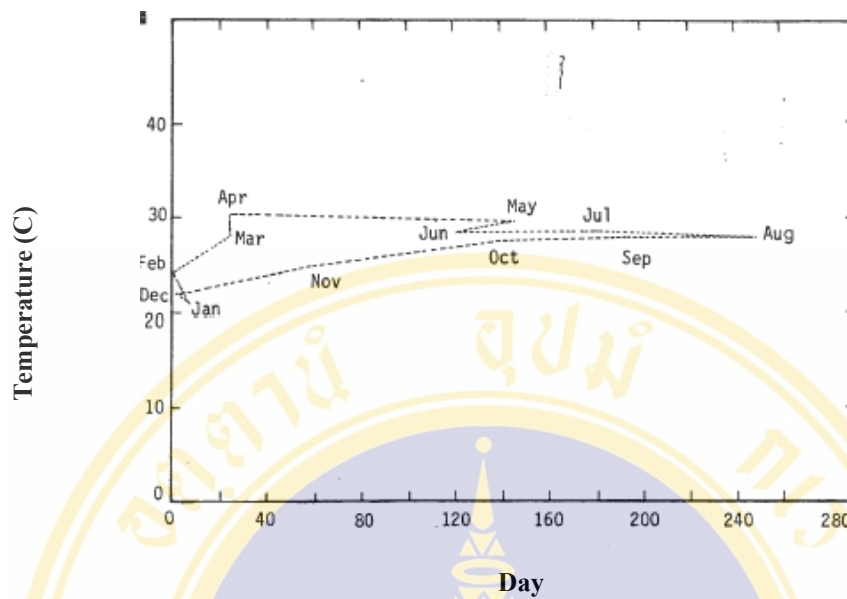


Figure 2.9: Hythergraph of Mae Moh Mining Area

2.1.5 Wind

Direction of prevailing wind changes according to the season. From October to January when the northeast monsoon is primary influence, while the southwest monsoon has an primary impact during February and May. Wind direction varies in all directions during the transition period of monsoon. The maximum recorded wind speed during March and April was 120 km/hr, and the lowest recorded wind speed was 5 – 6 km/hr during November and December. All recorded data were from Mae Moh station (Institute of Environmental Research, Chulalongkorn University, 1981)

2.1.6 Soils

2.1.6.1 Physiography of Mae Moh basin soils

The general outlook of Mae Moh basin soils is mainly undulating upland with some narrow ridges and valleys. Two main streams, Mae Moh and Huay Luang, run in the north-south direction and have accumulated the lower land with alluvial deposits along widening routes. Their tributaries have contributed in shaping the landscape resulting in narrow ridges and valleys, however the gravel beds of tertiary formation, located at the southwest corner of the basin, has the highest elevation in the basin.

Not much elevation different is observed in more than two thirds of the area as the elevation difference between the highest spots, high hills in the southwest corner and along Mae Moh stream in the southern portion is only 50 meters. Flat to almost top summits are common in this area. The slope of ridges and valleys is approximately 1 – 6 percent.

2.1.6.2 Soil Properties

Based on physiography, soils around the Mae Moh basin can be grouped into 6 mapping units, U1, U2, U3, A1, A2, and H. Tables 7 and 8 describe the properties of these groups.

In conclusion, the existing soils in the Mae Moh mine, in general, are dominated by relatively high pH and high calcium content since the area is partly surrounded by limestone mountains. The lignite coal exhibits the pH of 7.5. Phosphorus, an index for availability is very low in all soil profiles. The textures of soil vary from loam to clay (Institute of Environmental Research, Chulalongkorn University, 1981; EGAT, 1979; EGAT, 1993).

2.1.6.3 Soil properties at Dam Site and Saddle

(K. Engineering Consultants Co., Ltd., 1970)

- **Soil Classification**

By Unified Soil Classification System (USCS), representative soil is classified as CH group, inorganic clay of high plasticity. Very fine-grained soil compacted at suitable water content is considered low density. Summary of test results are shown in Table 2.3 and Table 2.4.

Table 2.3: Representative Fractions of the Overall Investigated AreaRepresentative Fractions of the Overall Investigated Area

MAPPING UNIT	% AREA	VOLUME ($\times 10^4 \text{ m}^3$)	ESTIMATED % SAND	ESTIMATED % SILT	ESTIMATED % CLAY	TOTAL	TEXTURE
U ₁	11.20	46.041	29.62	36.18	34.20	100.00	Clay Lo.
U ₂	56.52	232.242	20.10	30.55	49.35	100.00	Clay
U ₃	10.42	42.823	20.61	29.58	49.81	100.00	Clay
A ₁	14.79	60.75	15.02	36.08	48.90	100.00	Clay
A ₂	7.07	29.035	32.30	42.73	24.97	100.00	Loam.
Estimated representative fractions of the investi- gated area	total 100%		21.33	32.76	45.91	100.0	Clay

Note : Unit H is omitted and the % area of the other 5 units are recalculated to get a sum of 100 %

Table 2.4: Physiographic and Soil Units of Mae Moh Lignite Mine

Physiographic and Soil Units of Mae Moh Lignite Mine *

Symbol	Physiographic Unit Description	Symbol	Soil Mapping Unit Description	area(ha)
H	Hilly upland of gravel beds	H	--- ditto ---	3.82 % (16.32)
U	Undulating upland	U ₁	Convex to almost flat summit	10.77 % (46.01)
		U ₂	Sloping and slightly dissected land with narrow ridges	54.34 % (232.24)
		U ₃	Narrow valleys	10.01 % (42.82)
A	Alluvial Deposits	A ₁	Broad, almost flat alluvial deposits with low terraces of main streams	(14.20 %) (60.75)
		A ₂	Narrow, slightly concave to flat alluvial deposits of minor streams	(6.79 %) (29.04)

- **Main Soil Characteristics**

Water Content

Natural water content varies from 22.50% to 48.20%, while the optimum water content is 23.7% to 39.0% (small scale 4 inch compaction mold) and 25.0% to 38.7% (large scale 6 inch compaction mold).

Densities

Maximum dry density varies from 77.0 pounds per cubic foot (pcf) to 95.2 pcf (small scale) and 75.2 pcf to 93.0 pcf (large scale).

Shearing Strength

The Triaxial Test shows low shearing strength with $\tan\Phi = 0.673 - 0.190$

Imperviousness

Coefficients of permeability of soils by various methods (direct and indirect test) or by consolidation tests (saturated and unsaturated sample at optimum moisture content and maximum dry density) are determined to be 10⁻⁷ to 10⁻⁹ cm/sec. This indicates good to very good imperviousness or the soils can be classified as practically impervious soils.

- **Conclusions and Recommendations** (EGAT, 1981)

1. Soils in Mae Moh basin can be classified into 6 units, H, U1, U2, U3, A1, and A2. Soil unit U2 covers an area of about 54% of total area.
2. Soils are mainly to have clay texture with percentage of sand, silt, and clay of 20.10, 30.55, and 49.35, respectively.
3. Soils exhibit the reaction of slightly acid to neutral within the pH ranges of 5 – 7.
4. Organic matters are exceptional high for sandy clay loam of tropical savanna zone.
5. The amount of trace elements, Mn, Zn, Fe, Cu, are relatively high due to geochemical setting of the basin. However, under the natural pH condition of this area, these elements may not be available for plant uses and their toxicity would be apparent only under the pH condition of below 5.
6. Erosion hazard particularly that caused by high runoff, gully erosion and wind erosion is expected in the reclamation area unless plant cover is quickly established.

2.2 Utilization and Management of Fly Ash

Research of fly ash for use in Portland cement concrete was first published by Davis and associates in 1937, during the time fly ash became available in quantity from electric power plants. Their work served as the foundation for early specifications, methods of testing, and use of fly ash (ACI 232-2R-96). At the beginning, fly ash was used to replace the more expensive cement, however it was found to improve other properties of concrete. Research on fly ash in other uses has been conducted more extensively when the number of coal power plants increased, especially in the 1960s and 1970s, partly in response to the dramatic oil price increase.

Currently, many studies of fly ash have been done with elevated interest all around the world. There is a wide range of possible utilization of fly ash. Wesche (1996) summarized the use of fly ash in the following categories: cement, binders with fly ash, precast concrete, bricks and blocks, lightweight aggregates, road construction, soil stabilization, asphalt-filler, fill, and waste neutralization and stabilization.

Fly ash has been utilized in various types of applications, however, the most quantity of fly ash has been utilized as construction materials associated with cement and concrete work. Smink and Heynen (2000) stated that on the basis of fly ash's physical and chemical characteristics, its deposits seem to be suitable for the production of construction materials. *'This use was considered to be the most sustainable as well as the economically best option for using this material.'*

In the United States of America, more than 800 million metric tons of coals is burned annually, generating approximately 75 million tons of coal ash, making it the fourth most abundant mineral resource and the sixth most abundant material for resource recovery. Recycling of coal ash could save the generators millions of dollars annually in disposal fees. Because of the volume of coal ash, the cost of storing it, and the opportunity to create profitable new markets, coal ash waste generators in the U.S. can be expected to exhibit great enthusiasm for waste utilization. Environmental concern about coal combustion residues has existed for a long time. The primary concern, according to the Electric Power Research Institute (EPRI), is the possibility that they will contaminate surface and underlying waters with several inorganic constituents that may detrimentally affect plants, animals, and human health. Coal ash also contains organic and radioactive constituents of potential environmental concern (Office of Environmental Services, Minnesota Department of Transportation, 1997).

Whereas, in India, nearly 90 million tons of fly ash is generated annually and almost 65,000 acres of land is presently occupied by ash ponds. Fly ash is abundant and still considered the cheapest fuel to generate power. However, the wide use of coal raises concerns over the environmental impact. Burning of coal pollutes air and generates green house gases, while fly ash accumulation could contaminate both ground and surface water. There is a strong effort to manage the large amount of fly ash. It includes revision and formulation of standards, the use of legislation, the application of fiscal incentives, and other means. It can also be done by enhancing the

electric-efficiency of the plant, adopting clean coal technologies and bulk utilization of fly ash in construction and other industries. Fly ash in itself is going to emerge as a major industry in the next millennium in India (ESMAP, 1999, Kumar et al., 2000 and Mathew, 1999).

Holtz and Eighmy (2001) gave a comparison on the utilization of recycled materials in highway constructions. These numbers included percentage of fly ash utilized in the United States and many countries in Europe. Such percentages are: 27% for the United States, with 14.6 million tons recycled, 88% for Germany, with 3 million tons recycled, 100% for Denmark, with 1.17 million tons produced and used, and 100% for the Netherlands, with 0.94 million tons produced and used. The numbers implied that factors influencing percentage of fly ash recycling are population density and aggregate resource availability, and in some cases the degree of industrialization.

Cannon (1968) investigated the proportioning of fly ash concrete mixes for strength and economy. The Tennessee Valley Authority developed a method for proportioning fly ash with cement to produce concrete of equal compressive strength at 28 and 90 days to concrete without fly ash. The samples included at least nine different suppliers of cement and eight different fly ashes. Four of these would not meet Federal and ASTM specifications. Effects of differing proportions of fly ash on water requirements, strength, and economy were given, as well as a discussion on the effects of fineness and carbon content of fly ash and variations in strength of cements on cement requirements. The substitution was made on a one-for-one basis, either by weight or volume. The results showed that fly ash incorporated concrete would have lower compressive strength at 28 days, but frequently had equal or higher strength than control mixes at 90 days and beyond. This led many designers to conclude that fly ash is only desirable or economical in mass concrete where strength is not the principal requirement. However, an exceptional approach was developed by Lovewell and Washa to proportionate fly ash mixes for equal 28-day strength to control mixes. In their method, amount of fly ash added was always exceeded that of cement removed.

Montgomery et. al. (1981) did a microstructure study on fly ash in concrete, involving a scanning electron microscope study and compressive strength evaluation of the paste fraction and covered a range of mixes containing various amounts of a single supply of fly ash. The study aimed at identifying the mechanism(s) whereby the incorporation of fly ash influenced the strength of lean concrete mixes suitable for use in the construction of concrete gravity dams. Test specimens were cured at 20°C and 40°C at intervals of 7 days up to three months. Although it was not possible to propose a firm hypothesis, the study suggested that the early age strength development was largely influenced by the physical presence of the ash particles rather than by a compositional change of the particles as a result of chemical reaction.

Diamond (1984) investigated the utilization of fly ash, mainly in the United States with its present status. The author stated that there were about 48 million tons of fly ash produced each year in the United States. Out of this amount, only approximately 8 million tons, representing about 17% of total production, were utilized. Almost half of the utilization went into the production utilities themselves. The other 4.5 million tons were sold for external utilization and approximately 60% of the sold amount were used in concrete-related application, mostly as a mineral admixture, rather than as a blended cement component or cement raw material. The author also provided a brief summary of typical properties of low-calcium (ASTM Class F) and high-calcium (ASTM Class C) fly ashes, as well as special reference to differences in potential utilization.

Manz (1984) investigated the utilization of by-products from western coal combustion in the manufacture of mineral wool and other ceramic materials. In this investigation, the author found that the ash by-products from combustion or gasification of western U.S. coals had chemical and mineralogical characteristics that lend themselves to utilization in ceramic materials. Laboratory and pilot-scale fabrication of four materials has been studied. Cyclone slag from four lignite-fired power plants and a dry scrubber ash have been fabricated into mineral wool insulation in a pilot-scale cupola. Extruded and fired mixtures of fly ash, clay and ground glass have produced ceramics with extraordinary high flexural strength. Ceramic glazed wall tile utilizing fly ash in place of clay have met most of the specifications for fired

clay tile. Both fired and unfired dry-processed brick containing 100% western fly ash met ASTM specifications for fired clay brick.

Idorn and Thaulow (1985) investigated the effectiveness of research on fly ash in concrete. The authors stated that energy crises and availability have for a decade funded extensive research and numerous conferences regarding uses of fly ash in concrete. The returns of these investments could be improved by more systematic characterization of fly ashes and of cements used with them, and by more conceptual approaches to further development of testing methods. Also considered is the incorporation of exploration of the energetics of fly ash hydration with cement and of the ways in which fly ash may improve the microstructure of cement paste, whether hydrated or as “micro-aggregate”. The authors also suggested a desirable changes of the planning of research and communication of research results.

Mehta (1985) investigated the influence of fly ash characteristics on the strength of portland-fly ash mixtures. Although modern thermal power plants are producing large amount of fly ash, which is generally quite suitable for use in concrete work, the fly ash utilization in the U.S. remained low due to the lack of quality control. This is because the current standard on fly ash do not contain specifications and test methods that are able to assess adequately the performance of a fly ash in concrete. Based on tests on 11 different fly ashes and direct determination of compressive strength of test mortars made with a fixed proportion of fly ash by weight of cementitious material, and a fixed ratio between water and the cementitious material, it seemed that the calcium content and the particle size distribution of the fly ash were the most important parameters governing the strength development rate in normally cured portland cement-fly ash mixtures.

Randall et al. (1996) investigated the utilization project of fly ash in fired-clay products such as building and patio bricks, ceramic blocks, field and sewer tile and flower pots. The objectives was to 1) have one or more plant-scaled tests of fly ash mixed with brick clay with 20% or higher of fly ash, 2) make laboratory-scale study to measure and model the firing reactions, and 3) do a preliminary study to evaluate environmental and economic benefits. The overall results were be published in later phase of project, while preliminary study showed ‘some level’ of commercialization.

Fly Ash Resource Center (2001) reported a history and possible utilization of fly ash. Fly ash utilization was begun in 1946 by Chicago Fly Ash Company as a construction material for manufacturing concrete pipes. The first large-scale fly ash utilization was the construction of the Hungry Horse Dam in Montana in 1949, while six others were constructed in the 1950's. Examples of fly ash incorporated works include Water Tower Place in Chicago, the Eisenhower Expressway in Chicago, the Dunsmuir Tunnel in Vancouver, Picasso Tower in Madrid, the Commerzbank Tower in Frankfurt, Puylaurent Dam in France, the Channel Tunnel between France and United Kingdom, the underground railway tunnel in Vienna, the East Bridge in Copenhagen, and Eindhoven Airport landing strip in the Netherlands. Possible utilization of fly ash includes pipe and autoclaved aerated concrete, Roller Compacted Concrete (RCC) in dams, high-pressured steam-cured block, sand-lime bricks, mineral filler in asphaltic roads, grouts (under-slab, tunnel linings, sewer relining), rock stabilization or filling of cavities, embankments and backfills, soil stabilization, road base, stabilized backfills (flowable fills), raw materials in concrete, lightweight synthetic aggregate in block and concrete, industrial mineral filler, industrial waste stabilization, growing materials for plants, anti-skid material for roads during winter, and road drainage medium.

Utilization and management of fly ash reviewed various types of utilization and many styles of management associated with fly ash. The literature suggested that although various types of utilization exist, the practical utilization (management) is concerned with utilization of fly ash as construction materials, due to obvious benefits. Other types of utilization are not as practical as some of them are still being researched. The study concentrates on utilizing fly ash as construction material or as cement replacement.

2.3 Mae Moh Fly Ash

2.3.1 Characteristics

By-products of Mae Moh coal-burning industry consist of about 80% fly ash, 20% bottom ash, and small amount of slag and gypsum from the flu gas desulfurization system. Among these by-products, fly ash receives the most attention from the industry and researchers due to its considerable amount of production, its

potentially desirable characteristics for reutilization, and its possible contamination to the environment. On the other hand, due to its relatively poor cementitious and uncertain properties, its large size, along with its relatively small amount of production, bottom ash is less likely to be utilized and studied, compared to fly ash. Studies of bottom ash for reuse in Thailand are very limited.

Fly ash is defined in Cement and Concrete Terminology (ACI Committee) as *‘the finely divided residue resulting from the combustion of ground or powdered coal, which is transported from the firebox through the boiler by flue gases.’*

Characteristics of fly ash and its current management could potentially cause human health risk due to three reasons: fly ash’s ingredient-rich property, a massive amount of existing fly ash, and the current practice of fly ash management.

Fly ash could cause large environmental and health impact due to its ingredient-rich characteristics. According to the Electricity Generating Authority of Thailand (EGAT) report in 1993, an analysis of Mae Moh fly ash by various methods showed that it contained unburned carbon, metal and non-metal oxides, rare earth and trace elements, some of which are heavy metals. An unofficial report from EGAT (1999) reveals that fly ash from Mae Moh source contains many heavy metals with concentrations that cannot be disregarded. The typical examples of concentration from leaching tests of such metals are arsenic (As, 449 µg/g), chromium (Cr, 93 µg/g), lead (Pb, 52 µg/g), copper (Cu, 118 µg/g), zinc (Zn, 518 µg/g), nickel (Ni, 282 µg/g), and silver (Ag, 62 µg/g). In addition, Hart et. al. (1995) investigated geochemistry and mineralogy of Mae Moh fly ash through the sequence of electrostatic precipitators ashes and found the maximum concentration of 352 ppm (As), 106 ppm (Ni), 105 ppm (Cr), 45 ppm (Co), 32 ppm (Mo), and 15 ppm (Sb).



Figure 2.10: Fly Ash



Figure 2.11: Fly Ash at Storage Site

Fly ashes from similar sources around the world also have the same trend of properties. Fly ash from Puertollano (Spain) was reported to contain ‘very high concentration’ of some heavy metals such as As, Cd, Hg, Pb, and Zn (Umana, 2000). Binotto et al. (2000) found that physical and chemical characterization of coal waste from Charqueadas and Sao Jeronimo Counties (Brazil) significantly influenced groundwater contamination, evidenced by acidic pH values, as well as, high values of

conductivity, total dissolved solids (TDS), sulfates, ferrous ion and metals (As, Ni, Fe, Co, Cr, and Mn). This evidence, along with numerous reports from other publications, shows that surrounding atmosphere, soils, water bodies of both surface and groundwater could potentially be harmed. And it is inevitable for interacting ecosystems to be damaged.

The massive amount of fly ash could cause environmental problems for extensive areas and various ecosystems. A simple calculation shows that in a 50 million-ton pile of fly ash, with average concentration of 500 µg/g of arsenic and 100 µg/g of chromium, there are 25,000 grams of arsenic and 5,000 grams of chromium scattering all over disposal site and the surrounding area. Although relatively low in concentrations, large amount of fly ash could lead to the accumulation or total effect that may play important role, especially for some unknown hazardous mechanisms that might have been going on for a long time, ready to go off. Current monitoring effort to keep concentration below certain limits is not adequate to assess the overall impact to people and the environment.

Fly ash could pose environmental hazard due to its treatment in uncontrolled manner. The practice done on-site for short-term dust reduction is by spraying water to fly ash on belt conveyors being transported. Some amount of dust is collected as particles at the plant, while some escape to surrounding atmosphere. There is runoff and spill of fly ash along several kilometers of distance to the storage site. At the storage site, it is possible that leachates from piling ash could reach groundwater level, as there is no confirmation report of existing liners. The storage site itself is open and vulnerable to rain and wind, the two important medium for weathering processes and reactions. Binotto et al. (2000) suggested that in some situation certain mechanisms could turn the heavy metal leachates to be much more concentrated and might affect the quality of groundwater.

Fly ash is very small in particle size, in the range of 1 to 150 microns (10^{-6} m), with spherical shape, and can be trapped or collected by many means (Nimityongskul et al., 2001). At Mae Moh Power Plant, series of electrostatic precipitators, 99.5% in efficiency, are connected to the 'flying' path to collect fly ash in arranged silos. Twenty five percent of lignite coal or an approximate amount of 9,000 tons of ash are

collected each day (Table 1 and Kokkamheang, 2001). This amount is equivalent to 270,000 tons a month and about 3.3 million tons per year.

According to the Electricity Generating Authority of Thailand (EGAT) Report in 1993, an analysis of Mae Moh fly ash by Auger Electron Spectrometry, X-ray Photoelectron Spectrometry, Secondary Ion Mass Spectrometry, Neutron Activation Analysis, X-ray, Fluorescence Analysis and X-ray Diffractometer shows that it contains the following constituents within varying ranges:

Oxides of:	Ca, S, Si, Al, Mg, Na, K, and Fe,
Rare earth elements:	As, F, Sn, Sb
Unburned Carbon	
Trace elements:	Li, B, Ti, V, Cr, Mn, Ni, Co, Cu, Zn, Rb, Sr, Y, Zr, Nb, and Ba

Most of fly ash is in form of quartz (SiO_2), Mg, Anhydrite, Mullite ($3\text{Al}_2\text{O}_3 \bullet 2\text{SiO}_2$), Anorthite ($\text{Ca}_2\text{Al}_2\text{Si}_2\text{O}_2$), Gehlenite and Clinopyroxene ($\text{Mg}_2\text{Si}_2\text{O}$).

Hart et. al. (1995) investigated the geochemistry and mineralogy of fly ash from the Mae Moh Lignite Deposit in Thailand. The authors investigated and reported the concentration of 21 elements in Mae Moh fly ash from three boilers, 75 MW, 150 MW, and 300 MW by instrumental neutron activation analysis (INAA). Also, concentrations of 10 major elements were found using the x-ray fluorescence (XRF). While the concentration generally increased from bottom ash through the sequence of electrostatic precipitator ashes (ESPA), As, Co, Cr, Ni, Mo, and Sb reached their maximum concentration of 352 ppm, 45 ppm, 105 ppm, 32 ppm, 106 ppm, and 15 ppm, respectively. Scanning electron microscopy coupled with energy dispersive spectroscopy (SEM/EDS) was used to identify element assemblages within discrete particles and particle morphology. It was shown that bottom ash consisted of large angular fragments with small amount of spherical particles. Successive ESPA was composed mainly of spherical particles, which decreased in average diameter with increasing distance from the boilers. Major elements identified by EDS were Al, Si, S, K, Ca, Fe, and Ba, with minor amounts of Mg, Na, Ti, Mn, and Sr. Aluminum, Si, K, and Ca occurred together and were present in most fly ashes. At the end, the authors

concluded that the methods of waste management should be dictated by the potential environmental hazards posed by the chemistry of the ash.

Sujjavanich et. al. (2000) investigated the duration effect of high curing temperature regime on strength properties of normal and fly ash concrete. The authors found that temperature had significant effect on the chemical reactions in concrete. Different trends of strength development were noticed, especially the first 24 hours. In conventional concrete, a reduction of strength is observed, while in fly ash concrete, a significant strength gain is observed. Forty percent strength gain was observed in fly ash concrete with 20% cement replacement, but higher percent replacement meant the higher variation in strength gain. The high-temperature curing had less effect on strength development after 72 hours. During 3 – 72 hours of high temperature curing, the relationship between fly ash concrete strength to strength at 91 days and logarithmic of time may be estimated as a linear function.

Nimityongskul and Tahir (1999) predicted the strength of fly ash-concrete based on chemical composition and fineness of binder materials. The authors introduced a model for predicting the 28-day compressive strength of concrete incorporating fly ash, taken into account the chemical composition and fineness of fly ash and cement. The relationships between the strength and water-binder ratio, and pozzolanic strength and fineness of fly ash were developed from the test results and subsequently incorporated in the model. The model was based on Feret's law and could predict strength as a function of solid volume of the hardened fly ash-cement paste. The solid volume resulted from four mechanisms: hydration of two silicates, pozzolanic reaction between silica and calcium hydrate, physical action of both the water-binder and fly ash-cement ratio, and effect of alkalis present in the binder on pore-filling. The model was then calibrated using strength data of 135 concrete mixtures prepared and from other researchers' works. The model predictions agreed well with the experimental results.

Tahir and Nimityongskul (1999) presented a model to predict the strength development of fly ash concrete by applying the present state of knowledge about chemistry of hydration and pozzolanic reactions. The factors taken into account are chemical composition, fineness, as well as characteristics of mixture composition.

According to this model, the fly ash concrete strength results from four interacting mechanisms. First mechanism is hydration of two silicates, C_2S and C_3S . The second mechanism involves pozzolanic reaction between silica, S and calcium hydrate, CH. The third mechanism is physical action of pore-filling controlled by water-binder and fly ash-binder ratio. The last mechanism is effect of minor chemical compounds. The model is calibrated using 135 specific experimental results and data from several researchers. It is postulated that whole of the fly ash concrete strength is resulted from the solid volume of CSH gel. The model predictions agree with experimental data published.

Kunavanakij (1998) reported that fly ash is a puzzling, which has cementitious property, constituting of various compounds. Typical chemical compositions of Mae Moh fly ash in 1992 are: 40.3% SiO_2 , 24.0% Al_2O_3 , 15.0% Fe_2O_3 , 11.2% CaO, 2.8% MgO, 3.1% SO_3 , 1.0% Na_2O and 2.6% K_2O . Physical properties (1992) include: specific gravity of 1.99, specific surface of 270.6 sq.m/kg, 0.64% ignition loss, 1261.2 kg/cu.m bulk density, pozzolanic index (7 days) of 90.6 and pozzolanic index (28 days) of 102.8. She also reported the possible advantages of fly ash concrete over pure cement concrete: increased compressive strength, increased workability and durability, reduced sulphate attack, decreased bleeding and segregation, reduced shrinkage, reduced heat of hydration, reduced alkali-Aggregate reaction and increased flexural strength.

Nimityongskul (1993) conducted a research on 'properties of fly ash concrete from Mae Moh Power Plant.' In the research, three samples of fly ash were used to make fly ash-cement mortars, with adequate amount of water to obtain the slump of 5 – 8 cm. Mechanical properties, as well as compressive strength and tensile strength were examined. The results showed that Mae Moh fly ash had low quantity of SiO_2 and Al_2O_3 , which retarded the compressive strength development in fly ash-cement mortars. Fly ash could replace portland cement to an extent as high as 35% in 1 : 2.75 and 1 : 3.5 binder to sand ratios. 'Suitable' fly ash amount with 35% replacement was 340 kg/cu.m. The tensile strength of fly ash incorporated mortar was higher than that of normal concrete.

2.3.2 Utilization

Due to its cementitious characteristics and other beneficial properties, recently, the Mae Moh By-product Management Section is able to sell large quantity of fly ash, at a price of approximately 100 Baht a ton, to customers from many parts of Thailand (Pakowong, 2003).

In Thailand, fly ash from Mae Moh Power Plant has been attempted for many applications, especially in the field of cement and concrete. Examples of successful attempts are the construction of Roller Compacted Concrete (RCC) at Pak Mun dam in 1993 (6,450 tons of fly ash used with 68% cement replacement by weight) and at the Mae Moh Power Plants during 1994 – 1995, construction of large parking and storage area at the Mae Moh Power Plant and other locations, as well as in the maintenance works in various places (Kokkamheang, 1992, 1993). Characteristics of fly ash alone and fly ash-incorporating mortars and concrete have been investigated and published by many authors (Nimityongskul, Jaturapitakkul, Kokkamheang, Kiattikomol, Kunayanakij, Tangtermsirikul, mostly in 1990s, etc.). Research in the area of design and modeling was also of concern (Chatveera and Nimityongskul, 1993 and Tahir and Nimityongskul, 1999). Examples of other applications include Self-Compacting Concrete (SCC), Low Heat Concrete (LHC), and Roller Compacted Concrete Pavement (RCCP).

Kokkamhaeng et. al. (1997) investigated the potential utilization of Mae Moh lignite fly ash as a cement replacement material. Since 1990, fly ash from Mae Moh Plant, meeting the ASTM C 618 Class C, has been found increasing in uniformity and chemical composition. This studied was done between 1993 – 1997 and was emphasizing on demonstrating a few construction methods, which utilized Mae Moh lignite fly ash in various concrete structures of the Electricity Generating Authority of Thailand (EGAT). Accomplished works consisted of the Roller Compacted Concrete (RCC) construction at Pak Mun Dam, the demonstration of Roller Compacted Concrete Pavement (RCCP) without steel reinforcement, and the demonstration of the application of the Self-Compacting High Performance Concrete (SC-HPC) in filling fresh concrete into formworks of complicated structures without any vibration. The percent of cement replacement was kept at least 50% at all projects and

demonstrations. All fly ash concrete had some superior properties such as the workability of fresh concrete, longer placing time before initial setting, low heat development, adequate 28-day strength and higher long term compressive strength, and direct cost reduction due to lower costs of binder and labor. As a conclusion, Mae Moh fly ash was considered having a high potential for using a cement replacing material in concrete works, in EGAT, other government and private sectors in Thailand, and even in other Indo-China countries in the near future.

Boonpanaid (1998) investigated the lead and zinc removal efficiency of activated carbons from coconut shell and coal fly ash from Mae Moh lignite. Adsorption isotherms mostly obeyed Langmuir model as kinetic studies showed that different times are required for each system to reach its equilibrium. Analyses for adsorption maxima were performed in two ways, one by using a linear transformation of Langmuir equation and the other by employing a commercial non-linear regression program, ENZFIT. The overall results showed that fly ash has greater capacity for metal removal than the carbon samples although its porosity is much less.

Cheeraroj and Jaturapitakkul (2000) investigated the use of bottom ash, from Mae Moh power plant, as a pozzolanic material. Physical properties, chemical composition, and compressive strengths of mortars with type I cement replacement of 0, 10, 20, and 30% by weight, both before and after grinding, were analyzed. The test result showed that physically, before grinding the bottom ash was large in size and irregular in shape. Grinding made bottom ash smaller and more spherical, thus lower porosity. The chemical composition of ground and unground fly ashes were similar to that of fly ash. The compressive strength of unground bottom ash mortars was much less than that of fly ash mortars, however bottom ash mortars gained higher strength after 60 days. From the tests, compressive strength of ground bottom ash mortar with 30% cement replacement was more than 80% of standard mortar at 7 days and increased to be 94% at 28 days. The authors concluded that ground bottom ash was an excellent pozzolanic material.

Chindaprasirt et. al. (2000) investigated the properties of compacted concrete containing Mae Moh fly ash and black rice husk ash. The test was undertaken using the modified Proctor method for compaction. The results showed that the optimum moisture content (OMC) and the density of the compacted concrete depended on the

compactability of the mixes and the gradation of the aggregates. The strength of the compacted concrete depended on the compaction and the hydration of the cementitious materials. The authors concluded that both fly ash and black rice husk ash could be used as pozzolans for partial supplement of portland cement in making the compacted concrete. When superplasticizer is added, the mixes were more workable while the compactability and compressive strength increased. The result provided good guideline for field application of roller compacted concrete (RCC).

Nontananandh and Wangtien (1998) proposed the selection of lignite fly ash for concrete: another look for potential utilization, with an objective to illustrate the effects of replacing lignite fly ash (LFA) for portland cement in concrete by using major chemical elements of fly ash as indicative factors. The investigation was on the hardening effects through the compression strength test and comparing of strength of concretes containing LFA with standard concretes. The self cementing characteristic of LFA as expressed in term of hydration modulus, which was defined as the ratio of CaO to summation of SiO_2 , Al_2O_3 and Fe_2O_3 , was proposed as a set index for the potential utilization of using LFA as a replacement for cement in concrete. The test results showed the changed physical and engineering properties of concrete resulting from LFA replacement. For the designed cube strength of 210 and 250 ksc, the early-age compressive strength of concrete containing 10 – 30% LFA replacement was greater than that of standard concrete. Fly ash concrete also showed the higher durability of concrete under repeated wetting and drying test. These could be explained by the Hydration Modulus for which the optimum was in the range of 1.40 to 2.25.

Kiattikomol et al. (1998) conducted a research project ‘classified fly ash for concrete utilization,’ to select good quality fly ash for utilization in concrete works. The resultant fly ash concrete must be at the same quality better or than the control mixes. The size segregation was done by cyclone, then sizes, density and chemical properties were examined. Then, tests were conducted to find influence of particle size to the mortar compressive strength. The results showed that the fineness or particle size has significant contribution to compressive strength. The finer the particle sizes, the higher compressive strength of mortar would result. It was found

that when the highest percentage of cement replacement for the finest (best) particles is 35% to achieve the same or better compressive strength than the normal control standard mixes.

EGAT (1996) utilized fly ash in many ways: sub-base in road construction, backfill, foundation work for sub-plant, and construction of Pak Mun dam. Research has been conducted to study potential utilization of lignite fly ash in construction work. Fly ash was used to replace portland cement with the proportion of 85:15 and 70:30 by weight and mixed with other concrete ingredients, sand, crushed limestone, powdered limestone, and water. The products were used as wall and floor materials. The experimental results showed that both types of application met the Thai Industrial Standards 58-2530 and 827-2531 and can be used as construction materials. These products were cheaper than normal concrete products, while did not affect the environment.

Sanguanroongvong (1996) investigated the removal of heavy metals from water by fly ash. Fly ash was used as an inexpensive adsorbent to remove nickel, cadmium, and lead in three different concentration of solution, with pH range of 3 – 10. It was found that the removal efficiency depended on pH, contact time, and metal concentration. At pH of 10, the removal efficiency was highest for all three metals of interest with percent removal of 99.52%, 99.12%, and 99.55% for Ni, Cd, and Pb, respectively. Physical properties, shape and size, of fly ash was also examined in this study.

Rojchungprasert (1999) studied on the quality improvement of concrete roofing tiles by utilizing fly ash. The sand and cement ratio was set at 3.6, 3.8 and 4.0, while fly ash usage was 0%, 10% and 20%. The superplasticizer was used at the quantity of 0, 0.67, 1.50 liters/100 kg of cement. The slabs made from different mixtures from varying parameters were tested for bending strength. The result showed that bending strength decreased with the increase of sand to cement ratio and/or the increase of fly ash usage. However, when superplasticizer was increased, the bending strength also increased. A simple economic calculation on the cost of mixtures was also given.

Pakowong (2003), an assistant manager of the By-products Management Section of the Mae Moh Plant and primarily responsible for the sales of fly ash, gave

relevant information regarding the sales and utilization of fly ash. He stated that almost all of fly ash sold is used in the ready mixed concrete industry. A list of fly ash buyers is attached in Appendix A, however the exact quantity of sales is commercially confidential. The largest portion of fly ash, approximately 50% of total sales, is regularly sold to Concrete Product and Aggregates Cooperation Limited (CPAC), the Siam Cement Group. Practically, all fly ash bought by CPAC is used at ready mixed concrete plants in all regions of Thailand. (Munmuang and Limprapa, 2003)

An interview of truck drivers revealed that on the average they will come to buy fly ash from the Plant once a week due to the distance and company policy/working schedule/rest period. However, for a short-distance transportation to local silos in Lampang and the Northern region of Thailand, some drivers may come to the Plant up to 2 or 3 times a week. This is the reasonable maximum frequency of transportation any truck driver would work.

The truck drivers would weigh in an empty truck, wait in line, drive to silos to get loaded with approximately 30 tons of net-weight fly ash, then weigh out and drive to their destinations. The process at the silos takes 10 minutes on average (central tendency exposure) for each truck, but it may take up to 15 minutes (reasonable maximum exposure). The weighing station and waiting area are open to ambient air with no additional concentration of dust (Pakowong, 2002 and Ponlit, 2003).

Saraviut Munmuang, products engineer and Weerapong Limprapa, product development officer at CPAC, gave related information on the ready mixed concrete plant, their customers and processes of CPAC ready mixed concrete industry.

Most of ready mixed concrete has a portion of fly ash mixed in it. Out of approximately 200 CPAC ready mixed concrete plants in Thailand, more than 150 have a silo of fly ash. There are 2 to 4 silos in a plant and one of them contains fly ash. For example a standard plant, usually located in Bangkok, has 4 silos, 3 containing cement and 1 containing fly ash. The transportation cost of fly ash to Bangkok is approximately 600 – 700 Baht per ton, which is much lower than the cost of cement of more than 2,000 Bath a ton.

Fly ash is used as cement substitute. While having lower cost due to the total fly ash cost of about 700 – 800 Baht a ton, the ready mixed concrete can be sold at about the same price of pure cement concrete. The process of mixing is not complicated. The only additional requirement is the transportation to silo and from silo to a mixing pot via pressured pipeline. A certain quantity of fly ash will be calculated and controlled by computerized system and sent to a mixing pot.

The process of incorporating fly ash in ready-mix concrete industry is similar among all field plants: loading the proper amount fly ash from silo to mixing machines, mixing cement, fly ash, water, and possibly other admixtures by spinning, and unloading mixed concrete to the trucks.

A mixing pot can contain about 1.25 cubic meters of final concrete volume. The ready mixed concrete will be in series of one-cubic meter mixing batch. The mixing process takes approximately 60 – 75 seconds. Up to 55 cubic meters of concrete can be mixed in an hour and up to 400 – 500 cubic meters of concrete can be sold daily. A typical average of a plant for daily sale of ready mixed concrete is 50 cubic meters (Munmuang and Limprapa, 2003).

During the process of mixing concrete, fly ash can be accumulating in air ready for inhalation. Dust concentration (PM-10) in air of the plants is regularly measured and can be used to estimate exposure and thus risks of workers involving in the mixing processes (Appendix B).

Once the concrete is properly mixed it is unloaded to a truck waiting below the mixing pot (Figure 2.12), then it is transported to the end users of fly ash incorporating products.

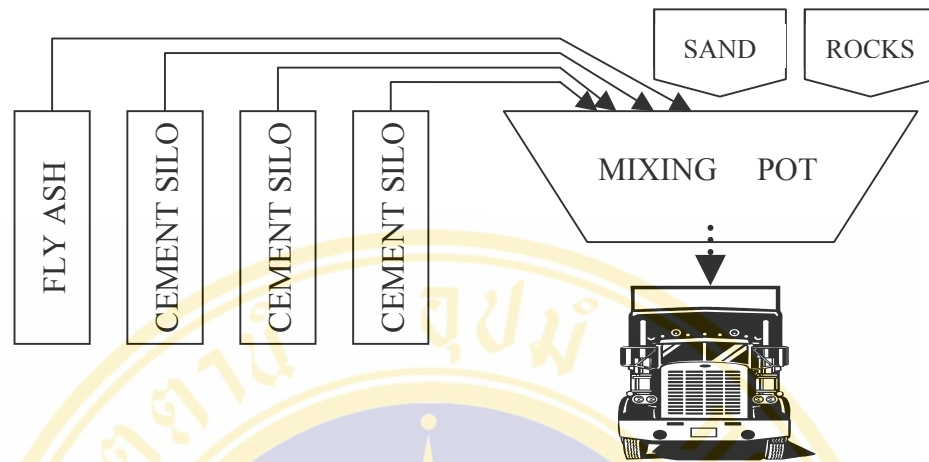


Figure 2.12: Processes at Ready Mixed Concrete Plant

There are varieties of ready mixed concrete customers. They can be generally categorized by the utilization purposes and the concrete compressive strength into the following groups:

General Building Structures: ready mixed concrete is used to build different structures such as floor, beams, and columns. These types of utilization usually consist of 20 – 30 percent of fly ash in concrete.

Road Surface: many road surfaces are currently using ready mixed concrete with a portion of fly ash from 10 – 15 percent. The cost of construction is lowered while gaining desirable properties such as cracks prevention. More amount of fly ash will retard the casting process and is not practical.

Special Purpose Structures: structures such as dams and large foundations require low heat of hydration process. Fly ash is utilized in large proportion, up to 50 – 60 percent, in these types of structures.

Throughout the ready mixed concrete processes, no additional cost is spent on fly ash, i.e. it needs no other preparation for the mixing. Most of the concrete products do not require other admixtures. This confirms a validity of the compressive and leaching tests because it simulates real situation, with no admixture, no other process, such as classification done to prepare fly ash.

2.3.3 Environmental, Economic and Technical Benefits

What we try to achieve in terms of managing the use of fly ash and its adverse impact to the environment is three-folded: to attain the management which is technically sound, commercially safe, and environmentally safe. Tyson (2000) estimated the benefits of using, in lieu of disposing, 21.1 million tons of coal combustion products in the U.S. during 1994 to be substantial. Principal benefits included: preserving about 20 million cubic yards of storage space; using fly ash to displace portland cement in concrete, thereby effectively avoiding about 4.7 million tons of CO₂ emissions, plus related environmental impacts, from the cement industry; and creating economic benefits estimated conservatively at \$1 billion.

The inclusion of coal ash in cement and concrete application could very likely and generally provide technological, environmental and economic benefits. Cement and concrete technological profits include the improved performances such as enhanced workability of fresh concrete, reduction of peak curing temperatures, reduction in water requirement, increase of the denseness of hardened concrete, protection against deleterious alkali-aggregate reactions, increased sulfate resistance, and decreased permeability, as well as the reduction of expansion due to alkali-silica reaction and improved durability of hardened concrete (ACI 232.2R-96).

Economically, the lignite coal ash could be regarded either as a profitable and valuable material or profitless and costly waste, depending on its utilization and management. Various studies for fly ash show that this by-product is beneficial and attractive for uses in many fields, especially in cement and concrete application. According to American Concrete Institute (ACI) 232.2R-96, *'fly ash is used in concrete primarily because of its pozzolanic and cementitious properties. These properties contribute to strength gain and may improve performance of fresh and hardened concrete. Use of fly ash often results in a reduction in the cost of concrete construction.'* Further, the savings for transportation cost and energy in the disposal processes, as well as the preservation of land area, are apparent.

ACI 232.2R-96 (1996) provided guideline for the use of fly ash in concrete due to its pozzolanic and cementitious properties. Fly ash contributed to strength gain and may improve performance of fresh and hardened concrete. Use of fly ash often resulted in a reduction in the cost of concrete construction. This report contained

information and recommendations concerning the selection and use of Class C and Class F fly ashes, which generally conformed to ASTM 618 requirements. Topics covered included a detailed description of the composition of fly ash, the physical and chemical effects of fly ash on properties of concrete, guidance on the handling and use of fly ash in concrete construction, use of fly ash in the production of concrete products and specialty concretes, and recommended procedures for quality assurance.

Mixing some amount of the ash by-products in concrete works could potentially be of economic advantages. The cost of fly ash is much lower than the cost of cement being replaced. Fly ash is sold about 100 Baht while cement costs more than 2000 Baht per ton. The economic advantage is even higher when the construction site is close to the ash disposal sites, and when cement is expensive due to long haulage distance (Pakinaga, 2003).

Environmentally, ash-incorporating cement and concrete mixtures enhance the healthier quality of the environment. Fly ash can be used to stabilize and solidify many types of hazardous wastes. The associated advantages are reduction of permeability, pH adjustment, pozzolanic activity, self-cementing, economy, free water reduction, and ease of application. Fly ash can also be used to immobilize toxic heavy metals and solidify or stabilize various oil wastes (ACI 232.2R-96). The possible leaching hazardous elements' atoms or molecules contained in ashes would be captured in concrete lattices. When greater amount of ash is re-utilized in other applications, such as concrete structure or construction, it is better off for the environment in the long run as more industrial waste is 'recycled' and utilized more efficiently. As a result, smaller amount of natural resources, such as the natural rocks and mountains, the major sources of raw material for cement industry, will be exploited.

Berry and Malhotra (1980) presented a critical review of fly ash for use in concrete. Fly ash has been used as a pozzolan to replace part of cement in concrete because it could achieve energy and cost savings, as well as, improved engineering properties of fresh and finished products. To effectively and economically use fly ash, it is important to understand the differences (especially in the strength development and the ways in which this may be influenced by methods of mix proportioning)

between fly and cement. When properly proportioned and placed, fly ash concrete generally showed improved workability, pumpability, cohesiveness, finish, ultimate strength, and durability. It also has been found that fly ash concrete added some advantages to high-strength concrete and has shown improved concrete performance for sulfate attack or deterioration due to alkali-aggregate interactions.

Lane and Best (1982) investigated the properties and use of fly ash in portland cement concrete. Such properties included physical and chemical properties of both fresh and hardened concretes, as well as, evaluation of engineering parameters. The authors also presented a procedure for mixture proportioning of fly ash concrete. The use of fly ash was proved to provide better than adequate performance in environments subject to freezing and thawing and acid attack. When compared, the advantages of using fly ash in concrete was far greater than the shortcomings that may be caused. Incorporating fly ash in concrete could result in lower unit prices, especially when ash-cement cost ratios could be kept below 40 percent. In addition, the authors suggested that fly ash concrete could be batched with the same level of confidence as concrete without fly ash. If fly ash came from reliable and constantly-loaded plant with proper mixing, its use could be resulting in high quality and large cost savings.

Idorn and Henrikson (1984) wrote a paper with the topic 'state of the art for fly ash uses in concrete.' The suggested an overview of accomplishments in recent research and of attractive further work for improvements of the uses of fly ash in concrete. Recognized advantages of fly ash in concrete are improved workability, reduction of peak curing temperature, protection against reactions with alkali-susceptible aggregates, and increased of the denseness of hardened concrete. The authors found trend towards more research about characterization of fly ash in relation to chemical composition and mineralogy structure. The impact on the rheology of fresh cement paste, on the energetics of hydrating system and on the microstructure of hardened cement paste was increasingly being studied. Although coherent research and development efforts were found commendable, more interaction with other branches of material sciences was desirable.

Ravina and Mehta (1986) investigated the effect of fresh concrete containing large amount of fly ash by replacing 35 to 50 % of cement by fly ash and observing workability, water requirement, bleeding, and settling time of lean concrete mixtures using two ASTM Class F and two ASTM Class C fly ashes. The results showed that workability of all concrete mixtures containing fly ash was better and water requirement (for obtaining designated slump of 2 in) reduced by 5 to 10% compared to the control mix. The bleeding was higher or about the same, depending on the type of fly ash and the mix proportions. Settling time was delayed for all mixes from initial settling time of 20 minutes up to 4 hours and 20 minutes, and the final settling time delayed for 1 hour up to 5 hours and 15 minutes, depending on types and amount of fly ash used.

Ravina and Mehta (1988) investigated the compressive strength of low cement/high fly ash concrete when they replaced 35 to 50% of cement by fly ash using two ASTM Class C samples and two Class F samples. It was concluded that in lean concrete, the use of large amount of fly ash, as replacement for both cement and sand, was highly beneficial. Particularly on lean concrete, depending on type of fly ash and mix proportion, fly ash has significant effect on properties of fresh and hardened concrete—it improved greatly workability, demanded less amount of water, higher or the same rate of bleeding, and slower setting time. To achieve the required strength of 2000 psi (14 MPa), while it took standard 28 days for reference mix, it took 35 to 170 days for concrete with above four sample of fly ash concrete.

Ukita et. al. (1989) examined the improvements in the properties of concrete utilizing ‘classified fly ash.’ Classified fly ashes (CFA) are those having maximum particle diameters of 20, 10 and 5 μm . Grading or type of fly ash determined its effect on concrete. CFA-concrete containing 15 - 30% CFA by cement weight required less water content per unit volume, while providing higher strength and water tightness, lower shrinkage and higher resistance to alkali, less bleeding, and higher rate of reaction. The compressive strength and abrasion resistance were increased at 91 days with finer particles of fly ash. At early ages the shrinkage of fly ash concrete was lower than the reference but at later ages the values were equal or higher.

Carette et. al. (1993) investigated the mechanical properties of fresh and hardened concrete incorporating high volumes of fly ash from the sources (8) and cements (2) in America. The analysis of the test results led to the conclusion that high-performance air-entrained high-volume fly ash could be produced with the fly ashes and cements used in the investigation. Such concretes had low bleeding, satisfactory slump and setting characteristics' and low autogenous temperature rise. The concretes also have shown excellent mechanical properties at both early and late ages with compressive strength reaching as high as 50 MPa at 91 days. Creep and drying shrinkage were observed to be low.

Stabilization/solidification is one proven and promising technique to manage environmental problems of fly ash disposal (Subbarao and Ghosh, 1997). Toxic substances would be fixed or captured within the molecular crystalline concrete structure or lattices, which reduces the toxic waste leaching concentration dramatically. In more technical terms, these waste components will precipitate in the form of insoluble compounds onto unreacted cement clinker grains preventing further hydration. Application of concrete incorporating fly ash can simultaneously help resolve the leaching problem. The stabilized fly ash can be accepted as a nonhazardous material for field applications (Subbarao and Ghosh, 1997).

In Thailand, utilization of fly ash in ready mixed concrete can provide economic and technological advantages. The cost of fly ash-mixed concrete is somewhat less than that of pure cement concrete, while providing other technological advantages. Lower heat of hydration and crack prevention are examples of such benefits. For these reasons, fly ash from Mae Moh Plant has been sold in increasing quantity within the past years. The price of fly ash is consistently raised from 60 Bath to about 120 Baht per ton from 2000 to present. The plant itself makes more profit from selling fly ash due to higher price, however the increase in price little affects the total cost of ready mixed concrete because the majority cost belongs to the transportation (Munmuang and Limprapa, 2003).

Environmental, Economic and Technical Benefits of utilizing fly ash stated in the literatures supported the focus of the study. There is a large potential benefits of utilizing fly ash in various types of works. Although utilizing fly ash tends to benefit

the environment by lowering the leachate concentration, we need to take a closer look at the effect on human health when we are closely ‘utilizing’ these products.

2.4 Compressive Strength and Leaching Tests

Concrete is a composite which contains varying amount of cement (of any type), fine aggregate (most commonly used is natural river sand), coarse aggregate (most commonly used is crushed stone), water, and in some cases, some admixtures (for special purposes). A mortar is a composite that consists of cement, fine aggregate, water, and sometimes, admixtures. Concrete and a mortar are different in that concrete has coarse aggregate as a constituent, while a mortar does not. In other words, a mortar is concrete with no coarse aggregate.

Due to the concrete’s typically high compressive strength, the most commonly intended purpose for using concrete structures and specimens is to resist compressive loads. The characteristics of a mortar, especially the compressive strength, which is closely related to its most applicable loading path, depend on the quantity and properties of all components: cement, water, fine aggregate, and possibly admixtures. In order for a mortar to behave cementitiously, the amount of all ingredients must be within limited ranges on which a cementitious behavior depends.

Along with their quantities in a mortar mixture, both physical properties and chemical activities of all ingredients have significant contribution to the mortar’s characteristics. Water-cement ratio, the proportion by weight of the added water and amount of cement in a mortar, is another important parameter that has great effect on the properties of a mortar. When a mortar is added with fly ash, its characteristics will, in addition, depend on the amount and properties of the added ash. Chemical and physical composition and properties of fly ash itself, as well as reactions and interaction with other ingredients, must be considered. In ash-incorporating mortars, a parameter ‘water-binder ratio’ is often used to define a proportion by weight of the amount of water to that of the binder’s. An amount of binder is defined as an amount of cement plus an amount of the replacing fly ash.

Halse et. al. (1984) proposed in a paper the development of microstructure and other properties in fly ash OPC systems. It was done by experimenting ordinary portland cement and fly ash blend cements containing 30% of fly ash. The samples were cast at room temperature with a w/s ratio of 0.45 – 0.47. The compressive strength and Ca(OH)_2 content were measured at several ages. In the samples with some amount of fly ash, the Ca(OH)_2 content reached a maximum value after 7 – 14 days thereafter decreasing as a result of pozzolanic reaction. This decrease in Ca(OH)_2 content followed dissolution of the fly ash surfaces and the augmentation of compressive strength by the fly ash.

Hansen (1990) investigated the long-term strength of high fly ash concrete. In the investigation, five fly ash concretes were found to gain considerable strength beyond 28 days when standard cured at 20°C (about the same to almost double and higher). However, strength development came to almost complete stop after 3.5 years, at which time the fly ash activity factors with respect to concrete compressive strength ranged from 0.86 to 0.93. In this investigation, hydration of fly ash concretes appeared to have stopped within 3 – 5 year period.

Sivasundaram et. al. (1990) examined long-term strength development of high-volume fly ash concrete. The author presented long-term data on the initial work carried out on high-volume fly ash at CANMET laboratories. A concrete block with dimension 1.5 m x 1.5 m x 1.5 m was cast indoors under controlled temperature conditions. The block contained 147 kg/m³ of ASTM type II cement and 187 kg/m³ of ASTM Class F fly ash, with the density of 2.5. The strength was observed over a period of 3.5 years. The block reached its maximum compressive strength of 70 MPa at 1.5 years and the modulus of elasticity was 47 GPa at 2 years of age. The chloride ion permeability tests showed negligible chloride ion permeability at the age of 3.5 years. The conclusion was that this type of concrete had excellent potential for use in massive concrete structures such as mat foundations, large retaining walls, piles, large columns and dams.

Demirbas et. al. (1995) study 11 different ashes from various sources in Turkey. The objective is to study the effect of lignite ash quality for uses as a mineral admixture in concrete. They find that the optimal lignite ash replacement is 25% by weight. When 25% by weight of cement is replaced by Class A (ASTM Class C)

lignite fly ash, based on 300 kg/m³ cementitious material, the 28-day compressive strength increased 24.3% compared to control mix. The authors concluded that the construction industry is keenly interested in replacing a large part of cement with beneficial lignite ash in concrete because of the economy that can be achieved.

Paya et. al. (1995) investigated physico-chemical characteristics of mechanically treated fly ashes. Fly ash was ground with laboratory mill for 10 to 60 minutes. The results showed that ground samples had higher specific gravity than original fly ash because of crushing cenospheres and porous carbon particles. Grinding strongly affected shape morphology as samples became less suitable as water reducing agent. Increasing of specific surface values could modify pozzolanic reaction rate with lime and would enhance early and long-term strength development. Further, increasing fineness was observed as samples showed greater reactivity towards water and higher acid neutralization capacity.

Singh and Garg (1999) investigated and formulated cementitious binder by judicious blending of fly ash with Portland cement as well as by admixing fly ash with calcined phosphogypsum, fluorogypsum, lime sludge, and chemical activators of different finenesses. The compressive strengths were examined and the authors concluded that the binders are eminently suitable for partial replacement (up to 25%) of cement in concrete without any detrimental effect on the strength. The results showed that fly ash can be used in the range from 45 – 70% in formulating these binders along with other industrial wastes to help in mitigating environmental pollution.

Galeota et. al. (1993) examined the mechanical and durability properties of high-volume fly ash concretes for structural applications. Fly ash from sources in Italy was used to prepare 4 concrete mixtures, with percent replacement varying from 0 – 50% by weight of total cementitious materials. A number of specimens were cast and tested for compressive strength, flexural and splitting-tensile strength, modulus of elasticity, fracture parameters, concrete-steel bond properties, drying shrinkage and durability. The experimental results showed that all fly ash concretes had adequate early age compressive strength at 3 days for structural applications. Beyond 28 days, the strength gap became smaller between fly-ash and non-fly ash concretes, and one

mix of fly ash concrete exceeded the strength of control mix. The dynamic modulus of elasticity at 28, 60, 90 and 365 days was lower for fly ash concrete, but was quite good for structural applications. Lastly, the flexural strength at 365 days was higher for fly ash concretes, and the splitting tensile strength was similar to that of control mixes. The conclusion was that high-volume fly ash concrete had considerable potential in a wide variety of structural applications.

Cabrera and Plowman (1999) investigated the influence of pulverized fuel ash on the early and long term strength of concrete prepared with four British pulverized fuel ashes as part replacement of ordinary portland cement. Mechanism and reactions that changed unconfined compressive strength were studied by XRD of C3A and C4AF extracted from hopper ashes replacement of cement up to 30% resulted in higher long term strengths (91 days) compared to control mixes. PFA-2 performed poorly compared with control mixes, while hopper ashes gave higher early strengths at varying percent replacement. The authors proposed that the mechanism by which strengths changed was a two-folded: first, a physical effect, which depended on the shape and specific surface of PFA and second, a chemical effect consisting of two distinct reactions. The first was a retarding of the hydration of C3A and C4A, which effectively reduced the heat of hydration and encouraged the formation of silicate hydrates. The second was a proper pozzolanic reaction that was detected as early as three days old by the use of a Scanning Electron Microscope.

Compressive strength and leaching tests are ones of most applied experiments used to characterize types and toxicity of mortar and concrete (including fly ash concrete). The compressive strength and leachate concentration of elements of interest suggest the types of fly ash concrete utilization, which are required for human health assessment, the latter step of the study.

Compressive strength tests will provide information on how the mortar, with varying amount of fly ash, will be used as types of utilization of concrete products, which largely depend on their compressive strength. Meanwhile, leaching tests will provide a necessary parameter, which are concentrations of leachate hazardous elements. Therefore, both compressive strength and leaching tests are important for the process of examining human health risks.

2.5 Arsenic and Related Health and Environmental Concerns

2.5.1 Arsenic and Toxicity and Contamination

Arsenic, As, has an atomic number of 33 (protons in nucleus) and atomic weight of 75. Inorganic and organic arsenic occur naturally in the environment, with inorganic arsenic being the most abundant form. Inorganic arsenic is associated with other metals in igneous and sedimentary rocks, and it occurs in combination with many other elements, especially oxygen, chlorine, and sulfur.

In addition to U.S. EPA regulation on maximum arsenic concentration of 0.05 mg/liter in drinking water, the Occupational Safety and Health Administration (OSHA) has established protective levels of 0.01 mg of inorganic and organic compounds per cubic meter of air inhaled (mg/m^3).

Past waste disposal practices worldwide have impacted arsenic concentrations in groundwater and surface water at waste disposal sites. Arsenic has been identified as a contaminant of concern at 916 of 1,467 Superfund National Priority List (NPL) hazardous waste sites (ATSDR, 1998). It is listed as the highest priority contaminant on the ATSDR/EPA list of the hazardous substances at NPL sites (ATSDR, 1997). The Thai Pollution Control Department (1998) also reported mutagenicity and teratogenicity effects of arsenic by observing chromosome malfunction and other malfunction of mice, respectively. There is a potential for release of arsenic to the environment and this needs further investigation.

Arsenic and its speciation in other oxidation states, arsenic pentoxide, arsenous oxide, arsenous trichloride, and arsine, are on the United States Environmental Protection Agency (EPA)'s list of extremely hazardous substances. In May, 2000, EPA proposed a new drinking water standard of 5 $\mu\text{g}/\text{l}$ for arsenic with commenting on feasible levels of 10 $\mu\text{g}/\text{l}$, and 20 $\mu\text{g}/\text{l}$. While, the Maximum Contaminant Level Goal (MCLG) for arsenic is zero. (EPA 815-F-00-011) Later, since January 2001, EPA has been finalizing a regulation to reduce the public health risks from arsenic in drinking water. The current drinking water standard of 50 parts per billion (ppb) is revised to 10 ppb to protect additional 13 people against cancer and other health problems, including cardiovascular disease, diabetes, and neurological effects. EPA will work with the National Academy of Sciences and the National Drinking Water

Advisory Council to release scientific and cost and benefit issues associated with the new regulations (EPA 815-F-00-015, 2001).

Of all leachable elements from fly ash, arsenic is considered the potentially most serious to human health. Arsenic has been classified by the U.S. EPA as Class A human carcinogen and the top of most hazardous substances list, based on 'sufficient evidence' from human data after arsenic's carcinogenic role was first noted over a hundred years ago. (EPA, 2000) An EPA report (2000) also stated that *'epidemiological studies...clearly show associations of arsenic with several internal cancers at exposure concentrations of several hundred micrograms per liter of drinking water.'* These organs include skin, bladder, lung, kidney, nasal cavity, liver and prostate. Further, arsenic is noted to be *'the biggest environmental contaminant in most of the soils where fly ash is applied'* (Qafoku et. al., 1999). Meanwhile, the current Thai standard for leachable total arsenic concentration by leachate extraction procedure is 5 mg/l. and the current drinking water standard for arsenic is 0.05 mg/l (MOI, 1997 and Department of Pollution Control, 2000).

Arsenic has a good history of toxicity. It used to be an efficient poison, before modern analytical techniques, because of its characteristics of being tasteless and difficult to detect. Natural concentrations of arsenic in human bodies are given in Table 2.5 (Johnson, 1972, cited in Reid, 2000). There are many arsenic symptoms due to its toxicity. Acute toxicity causes intense abdominal pain, weakness, staggering gait, hypothermia, and death. The fatal dose is 100 – 200 mg, depending on body weight. The chronic symptoms include weakness, loss of appetite, partial paralysis, and dementia. Gangrene and malignant neoplasms have also been observed (Bartova et al., 1973).

Table 2.5: Natural concentrations of arsenic in human bodies

Tissue	Arsenic conc./ ppm (wet weight)
Muscle	0.01
Bone	0.05
Skin	0.03
Blood	0.007
Hair	0.41
Nails	0.28

Inorganic arsenic is suspected to be carcinogen or co-carcinogen. (a promoter of carcinogen rather than an initiator) The chronic effect of inorganic arsenic is of the most concern due to the likelihood of exposure of normal human, i.e., it is more likely for people to expose to small amount of arsenic over a long period of time than high concentration in a short period (Andrea, 1977, cited in Reid, 2000).

There are many arsenic compounds with varying degree of toxicity. Arsenobetaine is an example of non-toxic compound due to its stable structure, with its LD₅₀ of over 10 g/kg in rats. Generally, arsenic salts are highly toxic by ingestion according to studies in rats and other animals. Arsenite salts are reported to be more toxic in rats than arsenate salts as their LD₅₀ are 10 – 100 mg/g and 1 – 20 mg/g, respectively (Reid, 2000).

There are many studies on toxicity of arsenic in plants. Arsenic toxicity in plants depends on arsenic form and thus its redox conditions of soil, especially for wetland plants with wide range of such conditions. Arsenite has high toxicity for radicular membranes due to its reaction with sulfhydryl groups of proteins causing disruption of the root functions of plants and cellular death (Speer, 1973). Arsenic in form of monomethyl arsenic acid (MMAA) can cause severe damage to succeeding rotational crops (Aarabi et al., 1998).

Some examples of arsenic problems include incidents in West Bengal, India, Louisiana, USA, and Ron Phibun, Thailand. ‘The biggest arsenic calamity in the world’ happened in West Bengal, India, where arsenic was found in drinking water of 30 million people, with concentration up to 700 ppb. Hair sample of population was found to have arsenic concentration up to 26 ppm. While, at least 800,000 samples exhibited arsenic chronic symptoms (Borgano and Greiber, 1971). In Louisiana, USA, wetland water was found to have arsenic concentration of 5 – 20 ppm. This had a damaging effect onto the environment. Charoenchaisri et al. (1996) reported significant arsenic pollution in Ron Phibun district of Nakhon Si Thammarat province, in the southern part of Thailand, which occurred in 1987. The source of pollution was thought to be from mining activities from the deposits and tungsten mineralization process. A follow-up study by the Thai Ministry of Public Health in 1991 found that

from samples of 2,400 students, 89% had excess arsenic in blood stream, and 22% had arsenic related skin disorders.

Ford et al. (1995) declared 'Final Project Report on Arsenic Biogeochemistry in the Clinch River and Watts Bar Reservoir, USA.' This study was done after preliminary screening of existing data showed concentrations higher than benchmark criteria for ecological risk assessment. The human health cancer risk value corresponding to a 10^{-4} risk is 4.7 $\mu\text{g/l}$ (62 nM). The study investigated the speciation, distribution, and mobility of arsenic in sediment, pore water, and the water column seasonally over a period of 3 years. This paper gave 3 reasons to be concerned about arsenic: 1) it occurs commonly in coal-bearing rock and waste products, such as fly ash associated with the burning of coal, 2) it is classified as a Class A carcinogen by EPA, and 3) disposal of fly ash may have contaminated water and sediments in the Clinch River and Watts Bar Reservoir. The results showed varying degree of concentrations on water and sediments over many areas of the reservoir and where the river passed through.

Khanra et al. (1998) studied the phase mineralogy and leaching characteristics of coal fly ash in India to assess their safe disposal in abandoned coal mines. Toxic elements were leached by distilled water, strong acid and bases under different conditions (solid-liquid ratio, leaching time, pH) with temperature of 30 – 100° C. Results showed that concentrations of various metals in leachates depended on chemical natures, associated with mineral phases of ash and followed similar concentration profile to that of iron, especially in acidic condition. Distribution of metals depended on amount of unburned carbon and iron in ash. In alkaline medium leaching of iron and toxic trace element, except arsenic, was very negligible.

Borm (1997) studied the in vitro and in vivo data on coal fly ash and silica, with coal mine dust chosen as a reference. The study suggested genotoxic effects of fly ash, but epidemiological studies in fly ash exposed working populations have found no evidence for effects commonly seen in coal workers (pneumoconiosis, emphysema) with an exception of airway obstruction at high exposure. Coal fly ash, via in vitro and in vivo experiments, showed lower toxicity, inflammatory potential and fibrogenicity than silica and coal mine dust.

Mehra et al. (1998) studied the impact of fly ash from coal-fired power stations in Delhi, with particular reference to metal contamination. The Indraprastha and Rajghat Power Stations are both coal-fired stations, with ash content of coal used ranged between 38 – 47 percent. The main way of ash disposal from the stations was to mix with water making it slurry, and to pump through pipes to ash disposal ponds. Then, the supernatant from these ponds were discharged to the River Yamuna. The paper concluded that the contamination (metal toxicity) due to fly ash into the river caused the reduction of local populations of *Eichhornia crassipes*.

2.5.2 Mechanism, Fate, and Transport of Arsenic

Arsenic is a metalloid in group V of periodic table (while some literatures say that it is a heavy metal) , analogous to phosphorus and nitrogen. Sources of arsenic are of both natural and anthropogenic origins. An average crustal concentration of arsenic is 3 ppm, but it can be as high as 20,000 ppm in arsenic ores such as arsenopyrite (FeAsS) and orpiment (As_4S_6). Normal concentration of arsenic in soils is 0.1 – 40 ppm, while normal concentration of arsenic in the sea and fresh water are 1 – 2 and 0.01 – 7 ppb, respectively. In plants and animals, these numbers are 0.01 – 5 ppm (dry weight) and 0.1 – 1.0 ppm. Arsenic may be mobilized in two main pathways, atmospheric and aqueous. The main anthropogenic sources of arsenic contamination include smelting operations and fossil-fuel combustion. (Encyclopedia of Analytical Chemistry, 1995)

The chemistry of arsenic in aquatic environmental system can be very complicated. Depending on the redox conditions, four oxidation states for stable compounds exist, +5, +3, 0, and –3. However, in general, the most abundant form present in natural water is inorganic arsenate (+5), although biological activity can greatly contribute to speciation of arsenic. In terrestrial environment, the most common organic arsenic compounds are monomethylarsonic acid (MMAA) and dimethylarsonic acid (DMAA). More complex organic arsenic compounds, such as arsenocholine, arsenobetaine, arsenic containing lipids and dimethyl (ribosyl) arsine oxides, are readily formed in the marine environment and are generally stable. (Bartova et al., 1973)

Mahuli et al. (1997) published an article titled 'Mechanisms of arsenic sorption by hydrated lime.' While arsenic represents one of the trace elements from fossil fuel-fired power plants, it tends to remain in gas phase. This study attempted to find effectiveness of removing the gaseous arsenic by commonly used mineral sorbents. Investigation was conducted with hydrated lime sorbent to identify the mechanism of As/Ca interaction and the chemical state and characteristics of captured species. Calcium hydroxide, $\text{Ca}(\text{OH})_2$ was found to be the most effective in capturing arsenic. Such capture mechanism is not a simple absorption, but irreversible chemical reaction leading to a solid product, calcium arsenate.

Martel and Rentz (1998) analyzed the behavior of the heavy metals, As, Cd, Hg, Ni, and Pb by mass balance for each element during the operation of dry bottom boiler in a German plant, using four South African fly ashes with five different blends. An analysis of soot blowing on mass balance showed that it has only little influence on dust loading, particle size distribution of fly ash and heavy metal concentration in fly ash. A clear enrichment of the elements As, Cd and Pb in fly ash is observed below a particle size of 5 μm . While enrichment of heavy metals is affected both by coal type and load conditions.

Arsenic is noted by Qafoku et al. (1999) to be the biggest environment contaminant in most of the soils where fly ash is applied due to its immobility and strongly absorption to soils. But, in gypsum-and-phosphorus-amended soils, As may be much more mobile. Therefore the study investigates whether or not As becomes more mobile when $\text{Ca}(\text{H}_2\text{PO}_4)_2$ and CaSO_4 are used as leaching solutions. The result shows that arsenic concentration in leachate when $\text{Ca}(\text{H}_2\text{PO}_4)_2$ was used was ten times that of when CaSO_4 was used. A maximum of 800 $\mu\text{g/l}$ was found which is much higher than the 50 $\mu\text{g/l}$ for groundwater (drinking) standard. In fly ash, the portion of arsenate non-specifically adsorbed, therefore, As concentrations are with the acceptable limits. On the other hand, phosphate can compete with arsenate for available adsorption sites, both non-specific and specific. Therefore, phosphate displacement of both forms of arsenates increase As mobility in both control and fly ash treatment.

Six Spanish fly ashes were studied for mobility of water soluble trace elements in open and closed (heated at 90°C) systems. The objective was to reduce the content of undesirable species to enhance their potential application. Leaching rates of different impurities were arranged in descending order: $B > Mo > Se > Li > Sr > Cr \geq As = Ba = Cd = V > Rb > Zn \geq Cu = Ni = Pb > Co > U > Mn$. Although many cement elements exhibited higher leaching rates in open system than closed extraction, the difference concentrations from the systems was insignificant, except for the extraction ratios obtained for As and V in high lime fly ashes (Querol et al., 2001).

Hirsch et al. (2000) studied the speciation of combustion-derived particulate phase arsenic. Inorganic arsenic compounds produced during combustion was investigated under fuel-lean conditions. Results showed that at the temperature of 850 – 1100 K, in the absence of particulate, arsenic initially condensed as As_2O_3 rather than the thermodynamically favored As_2O_5 . Synthetic fly ash (0.25 μ m spherical silica), added to the experiment to simulate combustion, and doping of silica particles with small amount of calcium, did not affect speciation of arsenic. As(V) was observed in form of calcium arsenate only at this range of temperature. The conclusion was that the formation of As(V) in combustion systems required either the oxidation of As_2O_3 or the presence of calcium compounds, calcium acetate. Calcium silicate particles are capable of capturing As(V), but the extent is still unclear.

Jackson et al. (1999) investigated the trace element solubility in fly ash/organic waste, which intended to improve soil macro-nutrients while reducing odor. The studies examined trace element solubility and availability resulting from litter (PL) or sewage sludge (SS) to field plots at 100 and 129 Mg/ha for FA/PL and FA/SS, respectively. Soils solution concentrations of dissolved C, P, As, Se, Mo, Cu, and Cr were increased in FA/PL field plots. Leaf tissue data confirmed an increase in available As from the FA/PL mixtures.

Brunori et al. (1999) compared five different leaching/extraction tests for the evaluation of metal release from fly ash. Eight elements, As, Cd, Cr, Cu, Ni, Pb, Se, and Zn from highly homogenized source of fly ash reference, were considered. Many test parameters were considered to include liquid/solid ratio, pH, leaching elements,

stirring conditions, and duration time. It was found that pH seemed to have the greatest influence on metal release (leachates).

Gorman et al. (2000) investigated the successful erodibility of fly ash used as topsoil substitute in mineland reclamation. Although successful in improving mine-soil chemical and physical properties, however, the fine sand-silt particle size of fly ash may make it more susceptible than natural soils to detachment and transport by erosive processes. In addition, the high content of silt-size particles in fly ash may make it more susceptible to surface crust formation, reducing in reduced infiltration and increased surface runoff and erosion. Fly ash-wood waste mixtures, used as a topsoil substitute, were surface applied with 10% and 20% slope. Linear Erosion/Elevation Measuring Instrument (LEMI) was used and erosions values were found to be up to five times greater than the untreated minesoil. Erosion also depended on type and amount of ground cover.

An attempt was made to study the behavior of various metal ions release in water from two fly ash samples in India. The USEPA extraction procedure was used to determine the early release of several hazardous materials, however, it was found that these concentrations were within the limits for both ash. Experimental leachates exhibited dramatically lower concentrations when pH was changed from 3.0 to 8.0. In other words, trace elements are much more soluble in acidic conditions than basic conditions (Kanungo and Mohapatra, 2000).

Vallini et al. (1999) evaluated cocomposted coal fly ash on dynamics of microbial populations and heavy metal uptake using *Vicia faba* pot experiment in greenhouse conditions. Growth response to different amendments with coal alkaline fly ash or cocomposted fly ash mixed with lignocellulosic residues. Parameters being monitored were soil microbial populations, pH, electrical conductivity and heavy metal uptake by plants. The results showed that plant biomass production was not influenced by types of soils, while alkaline fly ash did not promote microbial growth when applied alone into soils. However, cocomposted fly ash tended to increase bacterial and actinomycetes counts in soils. Fungi were not affected by fly ash. The increase of soil metals in sandy soils. Heavy metals mobility did not cause change in the clayey soil where a high buffering capacity mitigated the effects of fly ash amendments.

Schutter and Fuhrmann (1999) investigated microbial response to coal fly ash under field conditions. In the study, fly ash was incorporated by conventional tillage to a depth of 40 cm into field plots, which were subsequently cropped with a fallow-corn-wheat rotation or continuous fescue. Nitrification doubled while number of denitrifiers increased 200 times in fly ash amended soils compared to normal soils. The lack of detrimental effects onto microbial microorganisms was possibly due to 1) reduction in fly ash soluble salt and trace element concentration with time, 2) the mild alkalinity of fly ash, and 3) the positive response of crops to fly ash amendments.

Mollah et al. (1993) examined surface and bulk studies of leached and unleached fly ash using XPS, SEM, EDS, and FTIR techniques. The surface and bulk characteristics of fly ash were examined by X-ray photoelectron spectrometry (XPS), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and Fourier transform infrared spectroscopy (FTIR), in acidic solution. The authors stated that studies have shown that As, Pb, Zn, Cd, Hg, Cr, Ni, Sb, S, Tl, Se, etc. in coal were likely to be concentrated predominantly in sub-micrometer-sized fly ash particle and have an even greater tendency to escape into the environment. They may be deposited in human respiratory system by inhalation and later entered to blood stream. The results showed that fly ash particles were relatively resistant to either chemical or physical changes due to attack by acidic leaching solutions.

Warren and Dudas (1988) wrote an article 'leaching behavior of selected trace elements in chemically weathered alkaline fly ash.' In the experiment, alkaline fly ash was leached with diluted sulfuric acid in a series of lysimeters. The weathered residues retrieved after leaching were determined for major constituents by atomic absorption spectrometry, while trace elements were examined by instrumental neutron activation analysis. The results showed some elements enriched in highly leached portion of the residue sequence, suggesting association with the resistant internal Si-rich glass matrix of ash particles. More than 80% of As and B was dissolved from the ash under acidic conditions. With an exception of B, all elements that were mobilized from the acidified ash residues were also attenuated in the alkaline residues in association with one or more of the newly formed secondary minerals.

2.6 Hazardous Identification and Dose-Response Assessment

2.6.1 Arsenic Pharmacokinetics

Pharmacokinetics describes the behavior of a chemical within a body, including absorption or uptake into a body via different routes of exposure, metabolism and distribution of the chemical or its metabolites within the tissues of a body, as well as rates and mechanisms of excretion or elimination from a body (CANTOX Environmental Inc., 1999).

2.6.2 Absorption

2.6.2.1 Absorption Following Oral Exposure

Factors influencing the absorption of arsenic from the gastrointestinal tract include: (U.S. EPA, 1984a,b)

- the specific speciation of arsenic compound under consideration
- the physical-chemical properties of arsenic, especially its solubility
- the magnitude of the dose
- the matrix in which the exposure is received, and
- the animal species, especially the physiological characteristics of digestive system

Greater than 95% of water-soluble inorganic trivalent arsenic may be absorbed from the human gastrointestinal tract (Coulson et al., 1935; Ray-Bettley and O'Shea, 1975; Pomroy et al., 1980). Similarly, results of animal studies indicate the soluble arsenic compounds are readily absorbed following oral exposure, based on proportions of the administered dose of arsenic recovered in the faeces, 68 – 98% in mice and monkeys, 60 – 90% in hamsters, 51 – 67% in rabbits and rats (Charbonneau et al., 1978; Vahter and Norin, 1980; Odanaka et al., 1980; Yamauchi and Yamamura, 1985; Marafante et al., 1987; Marafante and Vahter, 1987; Freeman et al., 1993, 1995, cited in CANTOX, 1999). While, reduced bioavailability is observed with the less soluble forms of arsenic in both human and animal studies (Marafante and Vahter, 1987).

Reported values of oral bioavailability of inorganic arsenic is considerably less for dust or soil matrix administered, 24% in rabbits, when normalized for concentrations of arsenic in urine following intravenous administration of the same compound (Freeman et al., 1993). Freeman (1995) investigated the bioavailability of

arsenic in soil and house dust in the vicinity of a mine and smelter facility administration to female *Cynomolgus* monkeys via gel capsules. He found the mean values for arsenic oral bioavailability in house dust and soil matrices to be 19% and 14% based on normalization for urinary concentration, and 10% and 11% based on normalization for blood concentration. While, Groen (1994) found the bioavailability of inorganic arsenic in a bog ore-containing soil matrix to be 8.3% in dogs, based on normalization for urinary concentration. Davis et al. (1996) concluded that the reduction of bioavailability for dust and soil was due to less solubility and thus less access for dissolution or uptake.

2.6.2.2 Absorption Following Inhalation Exposure

The fraction of arsenic absorbed by the lung is dependent on particle size and the chemical species of arsenic, as it affects transportation of particles into the lower regions of the lung. Published literature shows that key parameters affecting inhalation absorption are particle size, degree of deposition of particulate-borne arsenic in the lung, and specific arsenic compound and its solubility (CANTOX Environmental Inc., 1999).

Many researchers have studied about the role of solubility of the chemical species on absorption in the lungs through administration via intratracheal instillation. It has been reported that 95 – 99% of doses of soluble arsenic compounds were absorbed within the lungs within one day and 99.6 – 99.8% were absorbed within 3 days, following intratracheal instillation in rats and hamsters (Rhoads and Sanders, 1985; Marafante and Vahter, 1987). While, insoluble arsenic compounds were absorbed more slowly. Arsenic trisulfide, lead arsenate, and calcium arsenate are absorbed 98.7%, 55%, and 50%, respectively, after 3 days.

Approximately 64% – 74% of particulate-bound arsenic, such as fly ash, was absorbed by hamsters' lungs in 2 days after administration, while arsenate and arsenite were completely absorbed within the same period of time, when administered with an inert dust materials (Buchet et al., 1995). Buchet (1997) concluded that arsenic absorption by lungs depends on chemical species, particle size, and dust load in the lung.

Absorption of particulate-bound arsenic following inhalation depends largely on the dynamics of deposition, retention and clearance of airborne particles by the respiratory system. Based on airborne particle dynamic model, smaller particle of less than $2\text{ }\mu\text{m}$ in size are respirable and are retained in the respiratory system, while larger particles are cleared from the respiratory system by mucociliary action, swallowed, and would be subject to gastrointestinal absorption (U.S. EPA, 1984). While, Smith et al. (1977) suggested that absorption of particulate-borne arsenic to the gut may be more important route of exposure for a particle size larger than $5\text{ }\mu\text{m}$, based on human studies.

Holland et al. (1959) studied the deposition and absorption of arsenic in respiratory system of lung cancer patients by administering arsenic-74 and arsenite aerosol via cigarette. Approximate 40% of arsenic was deposited in lungs and 75% – 80% of this was absorbed (total of 30% – 34%). The U.S. EPA used the value of 30% to represent the fraction of inhaled and absorbed arsenic in humans (U.S EPA, 1989).

2.6.2.3 Absorption Following Dermal Exposure

In general, there are very few data on the absorption of arsenic compounds through the skin. Dutkiewicz (1977) conducted a study of the absorption of sodium arsenate through the skin of rats whose tailed were immersed in the solution for 1 hour. And based on the observation that arsenic concentrations in blood, liver, and spleen increased over 5 days after exposure, ATSDR (1993) suggested that arsenic may initially bind to the skin and then slowly be absorbed into blood stream even when the exposure was discontinued.

Wester et al. (1993) quantified the in vitro and in vivo absorption of inorganic arsenic in soil and water through the skin of humans and monkeys. The absorption from soil and water in monkeys were found to be 3.2% - 4.5% and 2.0% - 6.4%, respectively. While, in humans, the numbers were somewhat less, ranging from 0.8% to 1.9% in soil and water, respectively.

2.6.2.4 Distribution of Arsenic Species

Distribution of arsenic in a body depends on the routes of exposure. Studies by Vahter (1981) showed that oral exposure led to higher initial distribution to the liver. On the hands, distribution of arsenic after inhalation and intravenous exposure resulted in accumulation in the liver, lungs, muscle and gastrointestinal epithelium in mice, marmoset monkeys, and rabbits (Vahter and Marafante, 1983). A sufficient time is required to distribute arsenic among various tissues of a body, remaining with slight concentrations in human nail and hair following oral exposure (Kurttio et al., 1998).

The body reacts with arsenic species differently. Vahter and Marafante (1983) found that more arsenic was retained in the tissues when mice and rabbits were injected with arsenite than arsenate. This was believed to be due to stronger affinity of trivalent arsenic, As(III). Regardless of arsenic form administered, trivalent arsenic tends to be the primary from interacting and binding to tissues in most species (Vahter, 1994).

Pentavalent arsenic, As(V), may also interact with tissues. It may substitute phosphate in enzyme-catalyzed and become incorporated into bone (Mitchell et al., 1971). Arsenate tends to be rapidly cleared from the blood stream into the kidney, where it can be excreted or reabsorbed (Vahter and Marafante, 1988). These differences in distribution between trivalent and pentavalent arsenic result in different profiles of tissue interaction and retention, thus different toxic potency. Distribution of arsenic species within a human body is basically similar to most species studied (Vahter, 1994).

Jackson and Miller (1998) determined arsenic and selenium speciation in coal fly ash extracts by ion chromatography-inductively coupled plasma mass spectrometry. As(III), As(V), Se(IV) and Se(VI) in aqueous extracts of coal fly ash were investigated. As(III), As(V), Se(IV) and Se(VI) were resolved with retention time of 1.1, 2.9, 4.8, and 6.3 minutes, respectively. Their concentrations were found to be 0.072, 0.868, 1.174, 0.284 $\mu\text{g/l}$, respectively. At low pH, the predominant species were As(V), and Se(IV), with As(III) detected in low pH fly ashes. Extraction

of fly ashes at pH 5 altered the concentrations of total soluble As and Se, but did not affect the predominant As and Se speciation.

Stoewsand (2001) stated that waste materials such as sewage sludge, incinerator residue and fly ash were frequently placed on or near farmland. These materials often contained toxic inorganics such as heavy metals, or organic substance such as polyaromatic hydrocarbons. Some amount of toxicity can be taken up by growing crop plants and the levels could reach potentially dangerous concentrations. Animal feeding studies of these crops, soil chemistry, plant biochemistry, and processing are being analyzed as part of risk assessment and management of these wastes.

Lee and Hahn (1997) investigated geochemistry of leachate from fly ash mound collected from disposal mound in one of the major UK coal-fired power station. Ash mound has been disposed since the mid 1970's and is 'well-engineered and managed' with no leaking of leachate into the underlying aquifer. The leachates showed high concentrations of Ca, Na, and SO₄ and trace elements with recorded highest concentrations of 22.3, 24.8, and 16.9 ppm of B, Li, and As, respectively. The rate of infiltration of porewater in the ash mound was calculated based on the chemical data of porewater and fly ash. The analytical result of the leachate was processed with geochemical modeling program. WATEQ4F, and potential concentration limiting solid phases were identified. Concentration of As, Cd, SO₄, Cr, Pb, and B exceeded discharging limits regulated by National River Authority. This implied that leachate should be treated before discharging. Further, there are sites built when the construction standard was not as stringent as today's. Groundwater pollution might take place by leachate discharge.

2.6.3 Arsenic Toxicology

2.6.3.1 Animal Studies

Acute effects of oral arsenic exposure include vomiting, nausea, diarrhea, gastrointestinal haemorrhage, and death in animals. Oral LD₅₀ values for arsenite, arsenate and arsenic trioxide in rodents were reported in the range of 10 and 110 mg As/kg by weight (Saady et al., 1989). Based on gastrointestinal and renal effects in monkey, the lowest no-observed-adverse-effect-level (NOAEL) for short term (13

days) oral arsenic exposure was reported to be 2.8 mg As/kg body weight/day. The lowest-observed-adverse-effect-level (LOAEL) was 5.7 mg As/kg body weight/day (Heywood and Sortwell, 1979).

Studies regarding acute dermal toxicity of arsenic is quite limited, however, existing studies show that arsenic is not likely to cause lethality or systemic toxicity. No effects were observed in guinea pigs and rats following single dermal doses of 4,000 mg As/L of As(V) or 580 mg As/L of As(III), and doses up to 1,000 mg As/kg by weight as As(III) or As(V), respectively (Gaines, 1960).

Studies of the oral subchronic exposure to arsenic indicated gastrointestinal, hematological, hepatic and renal effects in rats, rabbits, and mice and cardiovascular effects in rats (NTP, 1989). The LOAEL for subchronic arsenic oral exposure was 2.3 mg As/kg body weight/day, in rabbits, while the NOAEL was 1.4 mg As/kg body weight/day (NTP, 1989). The NOAEL's for mice and dogs are 29.6 and 4.6 mg As/kg body weight, respectively (Neiger and Osweiler, 1989). Local hyperplasia and skin irritation in mice was reported as a result of dermal exposure of 2.5 mg As/kg by weight for 18 weeks, 11 times a week (Boutwell, 1963).

For chronic effects of arsenic, mortality has been reported in dogs and monkeys with administered dose of about 3 mg As/kg body weight/day, for 2 years in diet, and for 1 year in milk (Heywood and Sortwell, 1979). Byron et al. (1967) also reported hepatic effects, including enlargement of the bile duct and pathological lesions in rats, cardiovascular effects, consisting of reduction of stroke volume and cardiac output and increased vascular resistance in rats and rabbits administered As (III), while no effects were observed for the same dose of As(V).

Persistent changes in the concentrations of neurotransmitter substances in the brains of rats were also observed with chronic arsenic oral exposure (Nagaraja and Desiraju, 1993).

The NOAEL for chronic arsenic oral exposure was 1.2 mg As/kg body weight/day, while LOAEL was 3.1 mg As/kg body weight/day, based on the studies in dogs exposed to arsenic in the diet for 2 years (Byron et al., 1967).

2.6.3.2 Human Studies

Acute effects of arsenic ingestion in humans include gastrointestinal irritation (nausea, vomiting, diarrhea, and gastrointestinal bleeding) and mortality from fluid loss and circulatory failure or secondary to tissue damage (Saady et al., 1989). Minimum lethal oral dose in humans was reported as a range, 1 to 3 mg As/kg (Armstrong et al., 1984). Other acute and sub-acute effects include haematological effects (anemia and leukemia), hepatic effects (hepatitis and elevated serum transaminase levels), renal effects (proteinuria and elevated serum creatine), respiratory effects (haemorrhagic bronchitis), neurotoxicity (confusion, lethargy, headache, seizures, coma, peripheral neuropathy, acute demyelinating polyneuropathy) (Armstrong et al., 1984; Greenberg, 1996). Armstrong et al. (1984) gave the acute oral LOAEL in humans as 1 mg As/kg body weight/day for these effects.

ATSDR (1993) suggested that an indication of mortality is not likely to be of concern for arsenic inhalation, even at very high levels of 1 – 100 mg As/m³ at the workplace exposure.

Sub-chronic exposure of oral administration also can result in cardiovascular effects, gastrointestinal irritation, haematological effects, hepatic effects (mild hepatomegaly), and dermal effects (Franzblau and Lilis, 1989).

There was no NOAEL for sub-chronic oral arsenic exposure, while LOAEL was 0.05 mg As/kg body weight/day, based on observe human administration for 2 to 3 weeks (Mizuta et al., 1956).

Sub-chronic and chronic health effects for occupational exposures to arsenic dust via inhalation tend to be related with irritation of mucous membranes, and at high concentrations, the gastrointestinal tract (Morton and Caron, 1989). the effects usually discontinued with cessation of exposure. The NOAEL air concentration for sub-chronic inhalation exposure was 0.11 mg As/m³ via 2 months of inhalation (Ide and Bullough, 1988).

Chronic exposures, usually through environmental or occupational contamination for oral and inhalation have been investigated in many human population. Cardiovascular effects due to chronic arsenic exposure include Blackfoot disease, arterial thickening, Raynold's disease, ischemic heart disease and thrombosis. Increased mortality was also observed in several studies (Morton and Caron, 1989).

Hepatic effects included hepatomegaly, portal fibrosis and hypertension, bleeding from esophageal varices; central and vascular fibrosis; cirrhosis, ascites, and fatty liver. Other effects included melanosis, keratosis, hyperkeratosis, hypo- and hyperpigmentation, pigmentation changes, warts, and gastrointestinal irritation. While, neurotoxic impacts for sub-chronic and chronic ingestion included sensory and motor nerves defects. Indicating symptoms include muscular weakness, paresthesia, electromyographic abnormalities, functional denervation, mild peripheral neuropathy, and neurobehavioral abnormalities (Fincher and Koerker, 1987; Kiburn, 1997).

Induction of diabetes mellitus was observed as a result of drinking arsenic-containing water (Lai et al., 1994) and through inhalation at workplace (Rahman and Axelson, 1995), based on epidemiological studies.

The NOAEL for human chronic arsenic oral exposure was 0.006 mg As/kg body weight/day for drinking water, while the LOAEL (for abnormal pigmentation) was 0.01 mg As/kg body weight for drinking water for a period of 11 – 15 years. (Borgono et al., 1980) The chronic inhalation data did not support the selection of NOAEL, while the NOAEL (for Raynaud's disease) was 0.05 mg As/m³ in workers with 14 to 40 years of exposure (Lagerkvist et al., 1988).

ATSDR (1993) concluded that occupational exposure to arsenic dust was doubtful for the relevance of positive result for abnormalities in humans.

2.6.4 Arsenic Carcinogenicity

2.6.4.1 Animal Studies

An association between intratracheal instillation and increased frequencies of lung adenomas or carcinomas has been reported by Ishinishi et al., 1983; Yamamoto et al., 1987) The experimental animal database for carcinogenicity of arsenic compounds is limited, and generally considered inadequate, and without consistent demonstration of carcinogenic activity (U.S. EPA, 1998).

2.6.4.2 Human Studies-Oral Exposure

Brown et al. (1989) conducted a dose-response analysis of Taiwanese population by observing the incidence of skin cancer from inorganic arsenic exposure through drinking water. The unit risk of skin cancer at an exposure of 1 $\mu\text{g As/kg body weight/day}$ ranged from 0.0013 to 0.003 using a quadratic or linear mathematical model, respectively. These values are in general agreement with those estimated for the Mexican population. (with several confounding factors) While, Chen et al. (1992) investigated the incidence of lung, bladder, and kidney tumors in a Taiwanese population exposed to high arsenic concentration in drinking water (well). Assuming a linear dose extrapolation curve (Armitage-Doll model), the lifetime risk at 10 $\mu\text{g As/kg body weight/day}$ could be adjusted to determine an RsD at 10^{-6} risk, yielding RsD values ranging from 0.00083 to 0.0024 $\mu\text{g As/kg BW/day}$ for males and 0.00059 to 0.0028 $\mu\text{g/kg BW/day}$ for females. (with several confounding factors) In addition, Chiou et al. (1995) observed a significant relationship between arsenic exposure and cancers of lungs and bladders, with controlled age, sex, and smoking status. The study was done by observing 263 Blackfoot disease patients in a region of endemic arseniasis in Taiwan, in comparison to a group of 2,293 healthy people, using Cox's proportional hazards regression analysis.

Guo et al. (1997) indicated that arsenic may induce cell type-specific carcinogenicity as a result of a study of 243 Taiwanese people drinking water with high concentration of arsenic. While, Hsueh et al. (1995) observed a significant dose-response relationship between skin cancer prevalence and chronic arsenic exposure in residents of Taiwan in which arseniasis was hyperendemic. Exposure was indexed by residential duration, duration of consumption of high-concentration arsenic from well water, average arsenic exposure, and cumulative arsenic exposure. The overall prevalence of skin cancer was as high as 6.1% and increasing with age.

A study chronic exposure effects of 40,000 Taiwanese population, exposed to arsenic-contaminated drinking water, was done by Tseng et al. (1968) and Tseng (1977), in comparison with 7,500 people who drank water free of arsenic. The results indicated elevated skin cancer and incidence of Blackfoot disease, hyperpigmentation and keratosis, with possible vascular problem. Although the U.S. EPA criticized

weaknesses of these studies, it used them to derive an oral slope factor of $0.0015 (\mu\text{g As/kg BW/day})^{-1}$, corresponding to a drinking water unit risk of $5 \times 10^{-5} (\mu\text{g As/L})^{-1}$.

2.6.4.3 Human Studies-Inhalation Exposure

Many literatures indicated positive association between inhalation exposure to arsenic and lung cancer rates -- mainly exposed to arsenic trioxide (Pinto et al., 1977, 1978 and Axelson et al., 1978), mainly exposed to arsenate (Ott et al., 1974 and Sobel et al., 1988), and arsenic compounds (Matanoski et al., 1981).

The U.S. EPA concluded that based on epidemiological evidence, arsenic is a human carcinogen (for respiratory cancer in workers in the non-ferrous mining industry (U.S. EPA, 1984a,b and U.S. EPA, 1988) and derived four unit cancer risk estimates for inhalation exposure:

Welch et al. (1982) using linear model (U.S. EPA, 1984a):

Unit cancer risk = $4.9 \times 10^{-3} (\mu\text{g As/m}^3)^{-1}$ and calculated lifetime risk of developing cancer equal to 10^{-6} , RsD = $0.000067 \mu\text{g As/kg BW/day}$

Brown and Chu (1983a, b, c) using multi-stage model equation:

Unit cancer risk = $0.00125 (\mu\text{g As/m}^3)^{-1}$ and lifetime risk of developing cancer equal to 10^{-6} , RsD = $0.00026 \mu\text{g As/kg BW/day}$.

Lee-Feldstein (1983):

Unit cancer risk = $0.0028 (\mu\text{g As/m}^3)^{-1}$ and calculated lifetime risk of developing cancer equal to 10^{-6} , RsD = $0.00012 \mu\text{g As/kg BW/day}$.

Enterline and Marsh (1982):

Unit cancer risks for 0-year and 10-year = 0.00681 and $0.0076 (\mu\text{g As/m}^3)^{-1}$ and converted lifetime risks of developing cancer equal to 10^{-6} , RsDs = 0.000048 and $0.000043 \mu\text{g As/kg BW/day}$ for 0-year and 10-year, respectively.

Reference Dose (RfD) and Reference Concentration (RfC):

U.S. EPA (1998): Oral RfD = $0.3 \mu\text{g As/kg BW/day}$

Oral unit risk factor ($q1^*$) = $0.0015 (\mu\text{g As/kg BW/day})^{-1}$

Inhalation unit risk factor ($q1^*$) = $0.0043 (\mu\text{g As/kg BW/day})^{-1}$
or equivalent to $0.013 (\mu\text{g As/kg BW/day})^{-1}$

Dermal RfD = Oral RfD and $q1^*$ adjusted for bioavailability.

Where bioavailability for arsenic was assumed to be 60 – 75% for ingestion, 30 – 34% for inhalation, and 0.8 – 1.9% for dermal exposure. (CANTOX, 1999)

Examples of non-cancer health effects of arsenic include peripheral vascular disease (Blackfoot disease) in China (Tseng, 1977) with a result of skin lesions. In association with other cardiovascular problems such as hypertension, heart disease have been found to be associated with arsenic (Tsuda et. Al., 1995).

2.7 Human Health Risk Assessment

Risk assessment has become ‘an important analytical tool’ in environmental decision making. It maybe defined as ‘*the identification of potential adverse effects to humans or ecosystems resulting from exposure to environmental hazards*’ (EPA/600/M-91/034, 1992). The risk involved, probable injury, disease, functional deficits, or death, may be expressed in quantitative or qualitative terms (EPA/600/M-91/034, 1992). Due to information constraints of environmental and ecosystems, this study will be limited to human health assessment which will consider the comparative effects of fly ash utilization as construction material and its non-utilization or leaving it at the disposal site. Health risk assessment is one technique used to address the problem of the potential or development of health effects related to exposure to specific hazardous chemicals or activities (OSTP, 1984 and NRC, 1984). To investigate human health assessment for each option of utilizing fly ash, many steps are required: hazard identification, dose-response assessment, exposure assessment, and risk characterization (EPA/SAB-EC-90-021, 1990). Quantitative and qualitative risk assessment could then be used as a useful decision making tool.

EPA/540/1-89/002, Risk Assessment Guideline for Superfund Vol. 1 : Human Health Evaluation Manual (Part A), provides three basic parts for guidance on the human health evaluation activities that are conducted during remedial investigation and feasibility study: baseline risk assessment, refinement of preliminary remediation goals, and remedial alternatives risk evaluation. This guideline supports the investigation of utilization of Mae Moh fly ash to lessen the degree of conflicts and help solve such disagreement. In this case, the baseline risk assessment will be done for the fly ash storage, while the utilization of fly ashes construction materials is a representative remedial alternative. While applying EPA Human Health Risk

Assessment, whenever data or standards exist for study area or in Thailand, they will be used. However, according to international procedure, when parameters are not available, best estimates will replace them, many times in terms of ranges of values.

Uncertainty is present in all environmental problems. Environment risk assessment is a tool to make it practical to carry the problem analysis throughout by following the rules of probability (Vanclay and Bronstein, 1995). Environmental risk assessment is also known as probabilistic risk assessment and probabilistic quantitative risk assessment.

Human health and safety are important issues in the prioritizing decision making. Some previous implementations in this regard have resulted in wasted resources, unjustified fears, and social disruption. (Ahearne, 1993) and Gough (1990) reported risk assessment as a tool for more rational and effective environmental management. The United States Environmental Protection Agency (1993) also stated that risk-based strategy could identify actions which would result in the most risk reduction per unit expenditure and which uncertainties are most important for scientific study.

Carpenter (1994) put official responses to risk assessment in chronological order to give an overall perspective of risk assessment history. These responses included:

- 1980 The Scientific Committee on Problems of Environment (SCOPE) of the International Congress of Scientific Unions (ICSU) published the landmark report 'Environment Risk Assessment.'
- 1982 The European Economic Community issued 'the Seveso Directive' on potential industrial hazards, following a serious dioxin release incident in Seveso, Italy.
- 1984 The World Bank, after the Bhopal (India) methyl isocyanate disaster, issued guidelines and a manual to help control major hazard accidents.
- 1987 The Organization for Economic Cooperation and Development compiled a report on risk assessment in the OECD countries with sections on the nuclear industry, chemicals, petroleum processing, transportation of hazardous materials, and dam-reservoir projects.

The much-referenced Brundtland Report for the World Commission on Environment and Development (WCED) called for the further development of technology assessment and risk assessment methodologies in pursuing sustainable development.

1992 More than 50 commercial banks signed a statement, as part of their credit risk procedures for both domestic and international lending, they would recommend EIA and ERA.

Risk assessment may be defined as ‘the identification of potential adverse effects to humans or ecosystems resulting from exposure to environment hazard.’ It has become ‘an important analytical tool’ in environmental decision making. A part of risk assessment primarily concern about humans is human health risk assessment, which involves the following steps: (EPA/600/M-91/034)

- 1) Hazard Identification: determination of whether a pollutant adversely affects human health.
- 2) Dose-response assessment: determination of the relationship between the level of exposure and the probability of occurrence of adverse effects.
- 3) Exposure assessment: determination of the extent of exposure.
- 4) Risk characterization: description of the nature and the magnitude of risk, including the accompanying uncertainty.

Once risk has been determined by this decision making tool, risk reduction and prevention strategies will develop by integrating risk assessment with technical, political, social, and economic issues. Figure 2.6 shows the relationship between risk assessment and risk management.

Human health risk can be viewed in terms of cancer and non-cancer related diseases. Cancer traced to direct, involuntary exposure to environmental pollution is estimated to be about 2 percent of total cancer risk (Doll and Peto, 1981). Other causes are use of tobacco and dietary excesses, and lifestyle choices and genetic mutations.

The USEPA (1993) has sponsored the development of methods for estimating additional risk of cancer from exposure to some carcinogen, as several hundred chemicals have been evaluated using animals. The procedure involves exposing animals to high dosage (maximum tolerated) for a period of time to suspected

carcinogen, then observing the carcinogenic results developed. The percentage of animals developed cancer of each carcinogen concentration is recorded, while the slope of this curve is extrapolated to the low doses expected to be encountered by humans. With certain assumptions, this slope becomes a unit cancer risk factor, or potency, expressed in terms of $(\text{mg/kg/day})^{-1}$.

While non-cancer diseases caused by exposure to toxic agents are estimated by using a potency factor called a reference dose (RfD) or reference concentration (RfC), the maximum daily exposure unlikely to cause deleterious health effects. Animal testing is also required to obtain RfD or RfC. Because of the variety of effects that are associated with non-cancer diseases, morbidity categories are established for comparing health effects (US EPA, 1993):

Observable effects:	detectable but may not show a disability (change in enzymes or blood biochemistry, or low weight gain (in infants)
Serious effects:	development or behavior abnormalities and/or dysfunction of an organ
Catastrophic effects:	prompt death or shortened life, severe disability

Bailey (1985) wrote a dissertation with the title 'Site-specific Health Risk Assessment: Discussion of Methodologies at Coal-Fired Power Plants.' She discussed on the use of health risk assessment methodologies for analysis of potential groundwater contamination. Bailey mainly followed risk assessment methodology, prepared by the Electricity Power Research Institute (EPRI), focusing on Selenium contamination to groundwater, although some parts were not complete. The author concluded (and recommended) that 1) formal risk assessment required standardized methodology, such as the one applied in the report, 2) adequate trained and certified personnel were required to apply such methodology, and 3) flexible methodologies should be the primary approach despite some limitations.

Dudka and Miller (1999) published an article titled 'Permissible concentration of arsenic and lead in soils based on risk assessment., The authors claimed that establishing permissible concentrations for As and Pb is important due to their

toxicity, widespread contamination, and limited resources availability for remediation of contaminated soils. The USEPA pathway approach to risk assessment was used to evaluate safe concentrations of the two metals in contaminated soils. A direct soil ingestion by children was considered the most serious exposure route. The paper suggested a conservative concentrations of 40 and 300 $\mu\text{g/g}$ as permissible concentrations, without hazard to exposed organisms.

Wongyai (2000) studied 'the Environmental Fluxes of Arsenic from Lignite Mining' at Mae Moh Electricity Power Plant, Lampang, Thailand. The author analyzed many series of water from mining operation and natural reservoir by Hydride Generation Atomic Absorption Spectrometry. She found that arsenic concentrations were lower than the current standard. However, it was reported that some precautions should take place to prevent possible contamination.

Exposure is the condition of a chemical contacting the outer boundary of a human (U.S. EPA, 1992). Most of the time, the chemical is contained in air, water, soil, a product, or a transport or carrier medium; the chemical concentration at the point of contact is the exposure concentration. Exposure over a period of time can be represented by a time-dependent profile of the exposure concentration. The area under the curve of this profile is the magnitude of the exposure, in a unit of concentration-time (Lioy, 1990; NRC, 1990):

$$E = \int_{(t_1 - t_2)} C(t) \cdot dt$$

Where E is the magnitude of exposure, C(t) is the exposure concentration as a function of time, and t is time, $t_2 - t_1$ is the exposure duration (ED). If exposure duration is a continuous period of time, then C(t) may be zero during part of this time. Integrated exposures are done typically for a single individual, a specific chemical, and a particular pathway or exposure route over given time period.

2.8 RISK*ASSISTANT

*'RISK*ASSISTANT is a powerful, yet easy to use, set of tools and databases that allows you to estimate health risk from chemicals in the environment in particular settings.'* It was developed by the Hampshire Research Institute of Alexandria, Virginia, which is a non-profit scientific and educational institution, with sponsorship from many organizations, such as, the United States Environmental Protection

Agency, California Environmental Protection Agency, Delaware Department of Natural Resources and Environmental Control, etc.

Previous versions of this software have been used, for the past five years, by environmental professionals and educators around the world, to conduct and teach risk assessment. This current version, RISK*ASSISTANT for Windows, is designed to greatly expand the number of people and organizations capable of performing risk assessment with many more features for local people who are facing risks (RISK*ASSISTANT Manual, 1990). Many interesting overall features of RISK*ASSISTANT is attached in Figure 2.13.

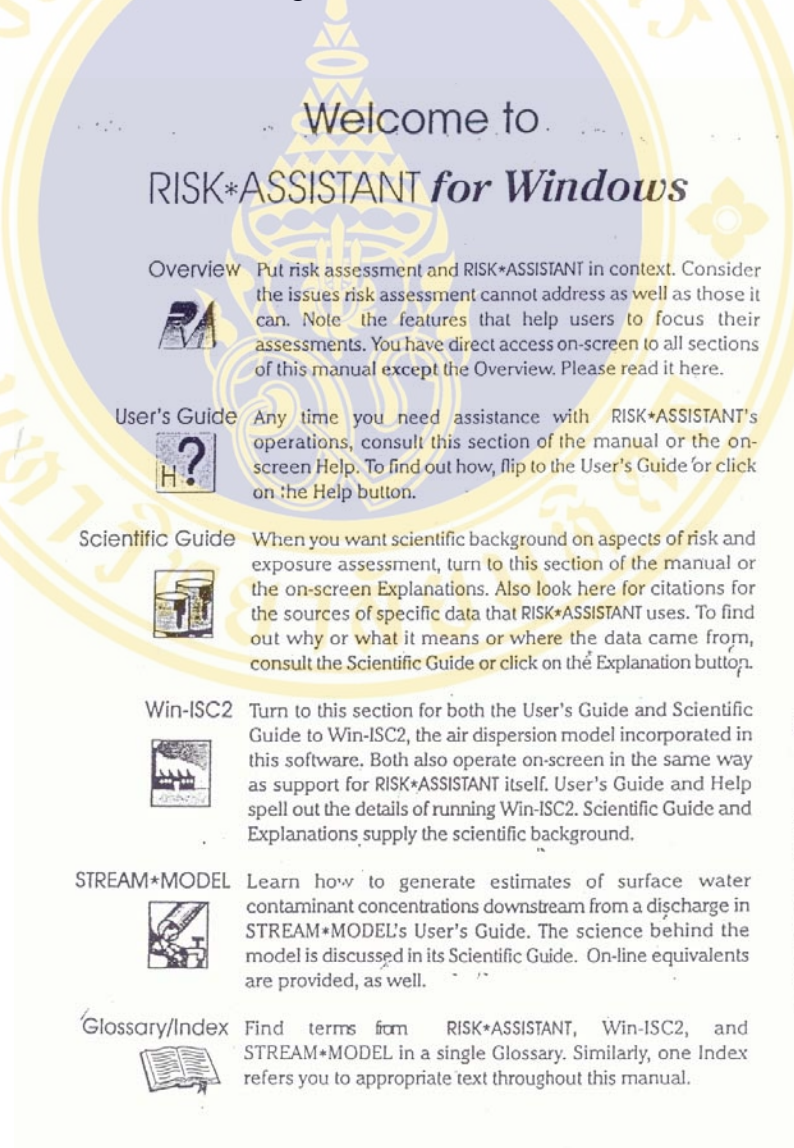


Figure 2.13: Overall Features of RISK*ASSISTANT

Once we are able to estimate the comparative risks between the storage of fly ash and utilizing it as construction materials by applying the U.S. EPA procedure, with best available knowledge and information, and verify resultant risks by the best software tool available (i.e. RISK*ASSISTANT), we will be more assured regarding the management and utilization of fly ash. Consequently, we will be able to locate potential risk areas/activities, and/or to suggest types of environmentally best options for types of utilization or remediation and/or treatment.

2.8.1 What is RISK*ASSISTANT?

RISK*ASSISTANT is a powerful, yet easy to use, set of tools and databases that allows you to estimate health risks from chemicals in the environment in particular settings. With RISK*ASSISTANT you need to know only the concentrations of chemicals present (or the amount of their release to the air) and something about local conditions of exposure to be able to generate your own estimates of the risks.

RISK*ASSISTANT has been developed by the Hampshire Research Institute of Alexandria, Virginia (a non profit scientific and educational institution), with generous sponsorship from:

- U.S. Environmental Protection Agency
- California Environmental Protection Agency
- Delaware Department of Natural Resources and Environmental Control
- New Jersey Department of Environmental Protection
- INFORM, Inc., and
- W. Alton Johns Foundation

For the past five years, environmental professionals and educators around the world have used previous versions of this software, RISK*ASSISTANT 1.0 and 2.0 for Windows offers many more features for these audiences. But, even more, RISK*ASSISTANT for Windows is designed to greatly expand the number of people and organizations capable of performing risk assessments-especially at the local level, where risk occurs.

Risks can only be estimated, not measured. But, even if they could be measured, there is no consensus on what to measure. RISK*ASSISTANT generates two types of risk estimates:

- for potential cancer-causing chemicals, the increased probability of individual's getting cancer from a particular exposure;
- for potential non-cancer toxic effects, a comparison of the expected level of exposure to an exposure that is assumed to be essentially without risk.

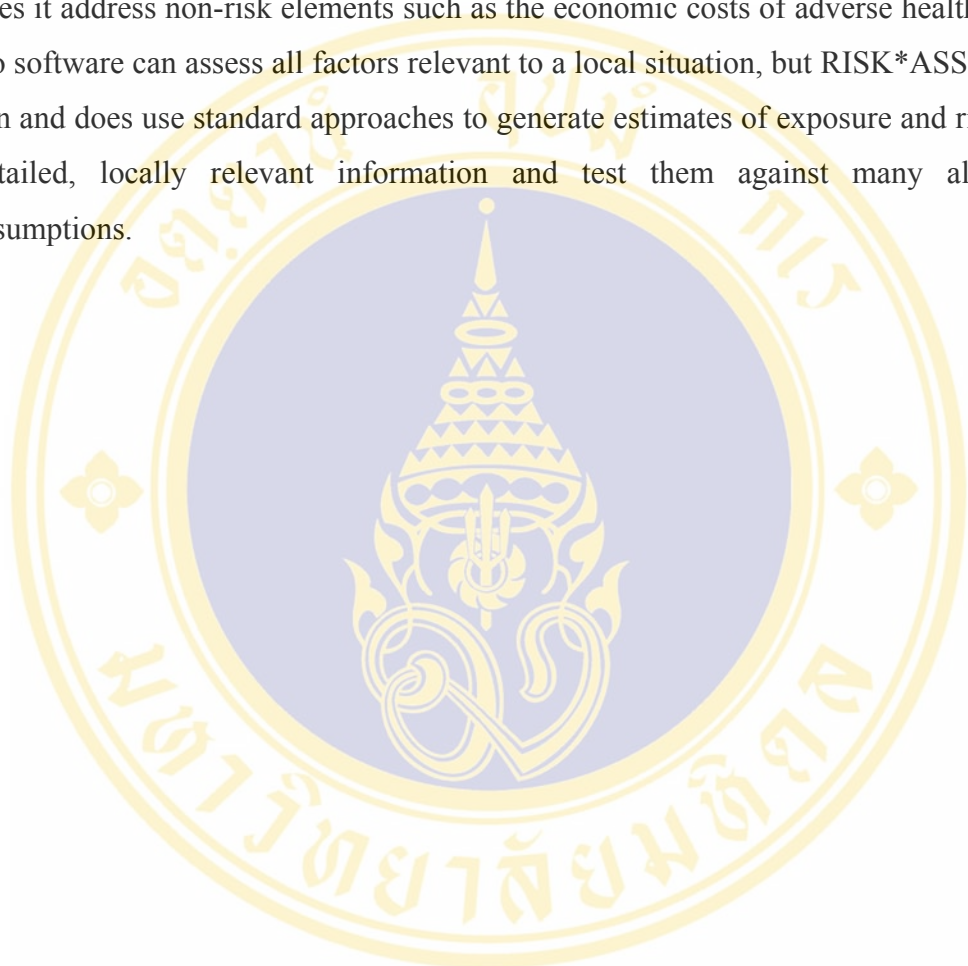
RISK*ASSISTANT uses these risk measures because they are the ones most often used in the U.S. Environmental Protection Agency (EPA) risk assessments. They are by no means the only possible measure of health risk, however. Other ways to assess the same adverse health effect include:

- total number of people affected, (population risk, rather than individual risk)
- the relative incidence of an adverse effect in populations known to be exposed with those not exposed,
- the ratio of the expected risk with the exposure to that expected without it,
- reduced life expectancy associated with the effect,
- income potential lost,
- quality of life lost or suffering incurred, and
- the costs to society from such an effect.

The perspectives gained from different risk measures, for the same adverse effect, can vary greatly. For example, several measures that weigh risk for society as a whole may imply a small concern, but if they result from very high individual risk to small number of people, that may justify a much greater concern.

2.8.2 RISK*ASSISTANT and the Issues of Risk Assessment

RISK*ASSISTANT lets you see the impact of different assumptions in your exposure and risk assessments, but it cannot eliminate the large uncertainties in such assessments. RISK*ASSISTANT cannot establish that risk is indeed the issue, nor does it address non-risk elements such as the economic costs of adverse health effects. No software can assess all factors relevant to a local situation, but RISK*ASSISTANT can and does use standard approaches to generate estimates of exposure and risk using detailed, locally relevant information and test them against many alternative assumptions.



CHAPTER III

MATERIALS AND METHODS

First, literature and preliminary site data, including those collected for a site visit, are examined to get overall information of the site. Data needed for human health assessment are characterized as those of sources, pathways, and receptors. (EPA/504/1-89/002, 1989) These information come from EGAT documents, published and informal papers, interviews with EGAT staff, internet searches, as well as, information from different governmental organizations, to include, maps of power plant site, the 1:50,000 topographic/military maps, recent 1:20,000 color aerial photo, land use maps, and articles and papers from various sources.

Then, the extensive site survey will provide more accurate information and a modification to preliminary data. Data on fly ash sales record will be assessed. The survey will also consist of collecting samples, according to planned testing schedule, with good sampling procedure, in adequate amount, from Mae Moh Lignite Power Plant, and transported them to proper storage with appropriate preservation.

Samples from top layer fly ash from different locations will be selected and collected by single random sampling event. Local site characteristics such as pH and temperature, will be measured on site, while parameters such as moisture content will be evaluated as soon as possible. Collection of surface water from different locations will follow the flow direction to the south-west, from Amphur Mae Moh to Amphur Mae Tha, and Amphur Koa Ka, respectively. Water samples will be preserved by nitric acid (2 ml of high-purity nitric acid per one liter of water) and stored at 4 degrees Celsius to prevent the loss of trace elements.

In this study, the procedures for compressive strength and leaching tests are based on the applicable ACI Standard Practice (ACI 232.2R-96) and ASTM Standard (ASTM C 618, ASTM C 109-90, and ASTM C 311-90). The variables in the compressive strength tests are percent of cement replacement and age of fly ash mortar after casting. (Figure 4) Concentration of total arsenic will be evaluated by using Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS) through standard

procedures. Research information from previous works will be examined to provide background knowledge on factors influencing mortar strength and leaching behavior. Sampling of fly ash data and testing schedule will be properly planned.

All gathered information, as well as, concentrations from testings, will be employed to evaluate human health risk for the two circumstances. The evaluation procedure in this study, highly complicated and multi-disciplinary, follows the guidelines by the United States Environmental Protection Agency, U.S. EPA. Unavailable data will be best estimated.

After the analysis of results, implementation of valid results relevant to decision making concerning fly ash utilization will follow.

3.1 Materials

3.1.1 Tools:

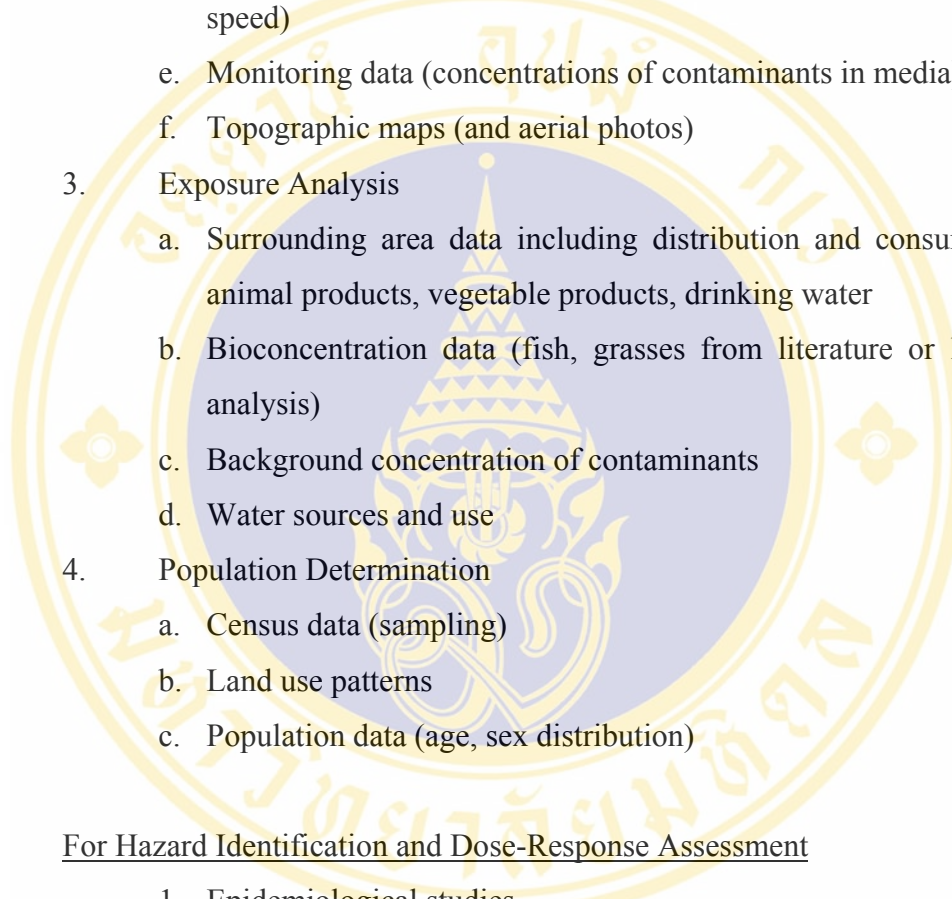
- Universal Testing Machine (UTM), standard setting
- Related American Concrete Institute (ACI) and American Society of Testing Materials (ASTM) manuals
- Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS), standard setting, with equipment and chemicals for total arsenic concentrations
- Related United States Environmental Protection Agency (EPA) manuals
- RISK*ASSISTANT software and user's manual

3.1.2 Data Requirement:

Typical risk assessment data requirements are shown below: (adapted from Bailey, 1985)

For Exposure Assessment

1. Source Generation (Emissions Determination)
 - a. Plant operations
 - b. Waste stream data
 - c. Monitoring data

- 
2. Environmental Transport
 - a. Pollutant fate properties
 - b. Site and surrounding area geology
 - c. Site and surrounding area hydrology (surface water flow)
 - d. Site and surrounding area atmospheric data (precipitation, wind speed)
 - e. Monitoring data (concentrations of contaminants in media)
 - f. Topographic maps (and aerial photos)
 3. Exposure Analysis
 - a. Surrounding area data including distribution and consumption of animal products, vegetable products, drinking water
 - b. Bioconcentration data (fish, grasses from literature or laboratory analysis)
 - c. Background concentration of contaminants
 - d. Water sources and use
 4. Population Determination
 - a. Census data (sampling)
 - b. Land use patterns
 - c. Population data (age, sex distribution)

For Hazard Identification and Dose-Response Assessment

1. Epidemiological studies
2. Animal bioassays
3. Short term tests
4. Structure/Activity Relationship
5. Dose-Response functions

3.2 Methods

3.2.1 Data Collection

In this step, an attempt will focus on collecting as much existing and accurate data as possible. There are two phases of data collection, preliminary and extensive ones. Both phases of data collection cover data required for human health risk

assessment, to include site-specific/local data and semi-regional (surrounding area) data. Site-specific data include physical, chemical, properties of fly ash, plant operations and activities, emission data, waste generation and stream monitoring, and meteorology. While, examples of surrounding area data are water consumption and use and its distribution, land use, and animal and plants products. The preliminary data collection lasts approximately one year prior to the extensive data collection at the site, which lasts for one week. All samples are taken during the day between 0830 and 1630.

3.2.1.1 Preliminary Data

Preliminary data are obtained from secondary data from many sources, including the site visit.

Table 3.1 : Examples of Preliminary Data and Sources.

Examples of Preliminary Data	Sources
Precipitation and intensity, wind	Related Governmental Departments
Geological/topographic data	Army Survey, Geological Resource Dept.
Current and Future Land use	Land Development Department
Population characteristics: number, distribution, water/food consumption, distance from source, etc.	Ministry of Interiors, Site visit
Characteristics of potential hazard elements	Literature review

Extensive Site Survey and Sample Collection:

Extensive Site Survey

This data collecting phase focuses on primary and local data by site survey and interviewing key informants, and to get required data unable to obtain in the first phase, and modifying obtained data for better accuracy. Data are obtained from local governmental agencies/organizations, enterprise (EGAT), and local people.

Population Survey (a part of extensive site survey)

Two groups of population are related to risk assessment: residential (including agricultural activities at residents) and occupational (workers and visitors at the power plant and storage site). Activities of both groups of people will be recorded.

Information will include information on population (gender, age, occupation, etc.) water consumption pattern and rate (drink, swim, etc.), working hours, etc.

Sample Collection

Samples for compressive strength and leaching tests, as well as, those for Graphite Furnace Atomic Absorption Spectrophotometry analysis, are collected in this phase.

Samples of fly ash to be tested for compressive strength and leaching tests will be collected from plants 4 – 13. A total approximate amount of 200 kilograms will be collected in a period of one week and transported to the laboratory in Bangkok and will be tested according to the schedule in Table 3.5 – Table 3.8.

While, the daily activity of all groups of exposed population will be surveyed and interviewed, to include their working schedule, drinking rate, etc. Secondary data on air quality, dust concentration in air, collected by the Electricity Generating Authority of Thailand and the Pollution Control Department.

3.2.2 Human Health Risk Assessment

3.2.2.1 Risk Assessment of the Storage of Fly Ash (Baseline Risk Assessment) (EPA/540/1-89/002) (Figure 3.1)

This step of human health risk assessment will lead to an achievement of the first objective of the study.

A) Data Collection and Evaluation

Gather and analyze the site specific data and surrounding data relevant to human health evaluation and identifying the substances present at the site that are the focus of the risk assessment process. Data for this step come from preliminary data and extensive site survey and sample collection, as well as, results from testings.

Determination of Total Arsenic Concentration by Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS)

The following determination of total arsenic concentration follows a technique by Jackson, 1958, cited in Visoottiviseth et. al., 2001. This method will be used to determine total arsenic concentrations of the samples of fly ash, surface water, soils,

grasses, and leachate water from fly ash-cement mortars. All chemicals used are analytical grade and Milli-Q water (Millipore) is used throughout the process.

The preserved samples of fly ash, soils, and grasses are required to be digested in the first step, while samples of surface water and leachate water are not. Digestion process is as follow; first the sample (1.00 g) has to be ground, then digested by adding 6 M HCl (10 ml) and leaving it at room temperature for 2 hours. Next, a solution of HCl/HNO₃ (3:1 v/v, 10 ml) is added and the mixture is heated at 80 degrees Celsius for 2 hours. After heating, the mixed solution is diluted with deionized water, filtered, and added with water to make the final volume of 50 ml. The solution is digested and prepared for the next step.

The next step is determination of total arsenic concentrations by Graphite Furnace Atomic Absorption Spectrophotometry. Samples ready for this step include surface water, leachate water from fly ash-cement mortars, and the prepared/digested solution from digestion process. In this step, acid blanks are analyzed in order to assess possible contamination. Standard solution, 100 g/l As, is prepared using diluted standard 1,000 mg/l As as sodium arsenate (Na₂HaSO₄.7H₂O) with 1% nitric acid. Palladium 1,000 mg/l was used as matrix modifier. AAS(Perkin-Elmer Analyst) and graphite tubes with L'vov platforms are used to determine arsenic concentration. The radiation source was as As electrodeless-discharge lamp operated at over 300 mA; the wavelength is 193.5 nm and a 0.7 nm spectral band width is used. The operating conditions for analysis are as follows:

Table 3.2 Graphite Furnace Atomic Absorption Spectrophotometry Operating Conditions.

Step	Temperature (°C)	Ramp/Hold Time (sec)	Argon gas flow (ml/min)
1. Drying	120	10/30	250
2. Pyrolysis	1,200	10/30	250
3. Cooling	20	5/5	250
4. Atomization	2,300	0/5	Stop flow
5. Clean up	2,400	1/5	250

B) Exposure Assessment

Estimate the magnitude of actual and/or potential human exposures to substance(s) identified in the former stage, the frequency and duration of these exposures, and the pathways by which humans are exposed. Reasonable maximum estimates of exposures are developed for both circumstances. This stage of assessment involves analyzing contaminant releases; identifying exposed population; identifying all potential pathways of exposures; estimating exposure point concentration for specific pathways, based on environmental monitoring data and predictive chemical modeling results; and estimating contaminant intakes for specific pathways. The results of this assessment are pathway-specific intakes for current and 'optional' exposures to individual substances. Data required for this step are collected during data collection process and from the results of testings.

C) Toxicity Assessment

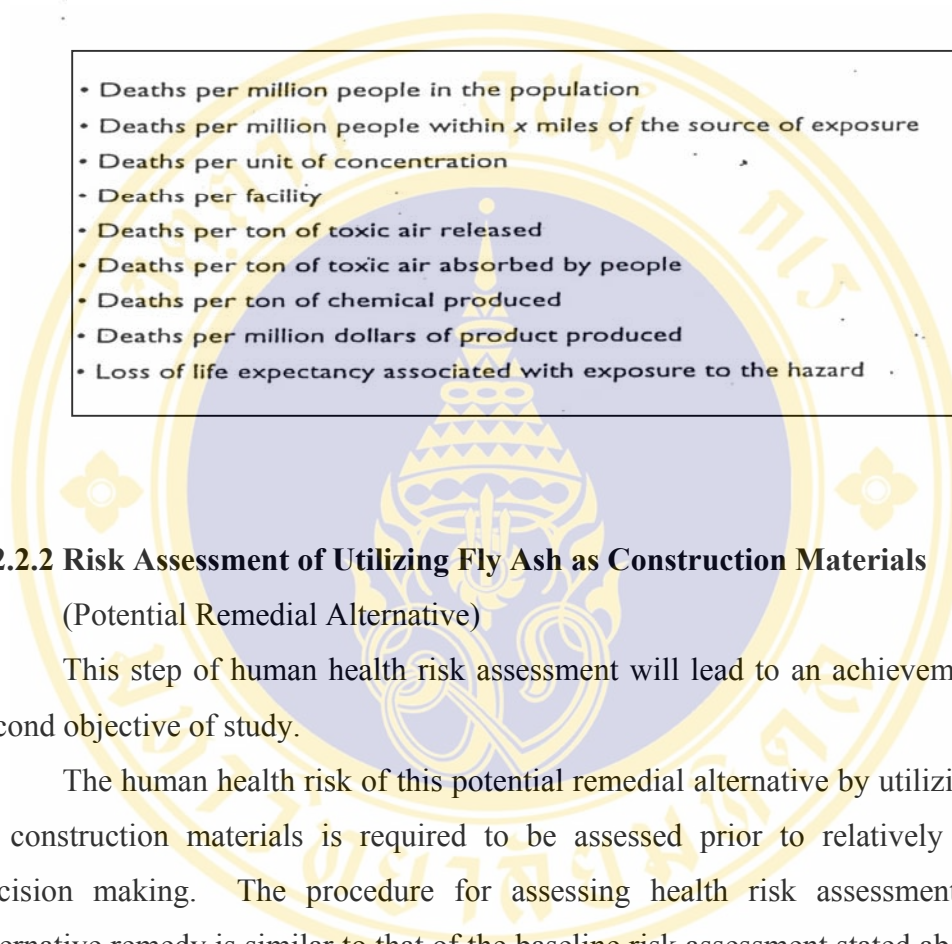
This stage considers: 1) the types of adverse effects associated with chemical exposures; 2) the relationship between magnitude of exposure and adverse effects; and 3) related uncertainties such as the weight of a particular chemical's carcinogenicity in humans. The U.S. EPA relies heavily on existing toxicity information developed for specific chemicals. Toxicity assessment consists of two steps, hazard identification and dose-response assessment. Hazard identification involves determining whether exposure to an agent can cause an increase in the incidence of an adverse health effect, such as cancer and birth defect. Dose-response assessment is a process of quantitatively evaluating the toxicity information and characterizing the relationship between the dose of the contaminant administered or received and the incidence of adverse health effects in the exposed population at different exposure levels. Concentrations of total arsenic from experimental analysis are relevant to both steps of this stage of assessment.

D) Risk Characterization

In risk characterization, summary and combination of outputs of exposure and toxicity assessments to characterize baseline risks (both in quantitative expressions and qualitative statements) are laid out. During this stage, chemical-specific toxicity information is compared against both measured contaminant exposure levels and those levels predicted through fate and transport modeling to determine whether or not

current or alternative levels at or near the site are of potential concern. Quantitative expression of risk can be reported in many ways (Table 3.3).

Table 3.3: Quantitative Expression of Risks



• Deaths per million people in the population • Deaths per million people within x miles of the source of exposure • Deaths per unit of concentration • Deaths per facility • Deaths per ton of toxic air released • Deaths per ton of toxic air absorbed by people • Deaths per ton of chemical produced • Deaths per million dollars of product produced • Loss of life expectancy associated with exposure to the hazard

3.2.2.2 Risk Assessment of Utilizing Fly Ash as Construction Materials

(Potential Remedial Alternative)

This step of human health risk assessment will lead to an achievement of the second objective of study.

The human health risk of this potential remedial alternative by utilizing fly ash as construction materials is required to be assessed prior to relatively confident decision making. The procedure for assessing health risk assessment for this alternative remedy is similar to that of the baseline risk assessment stated above. Data collection, both from preliminary data and extensive site survey, provide information for this procedure. However, various data and information have to be modified with respect to an alternative scenario. Previous studies, results of compressive strength and leaching tests, as well as information on fly ash sales record and potential market for construction, tell us about existing and potential types and quantity of utilization. While, leaching test and GFAAS analysis reveal the concentration of total arsenic possible exposed to humans in their existing and potential fly ash concrete utilization.

Compressive Strength Test (ASTM 109-90)

The object of this test is to find compressive strengths of fly ash-cement mortars at varying percent of cement replacement and age after casting. Other parameters, which have an effect on compressive strength, will be held constant. Parameters held reasonably fixed are cement type (Portland cement, type I), type of aggregate (natural sand), type of water (tap water), type of fly ash (Mae Moh source), admixtures (none), sand to cement ratio-S/C (kept at 3.0), water-binder ratio (kept at 5.0), as well as, fineness and degradation of fly ash (in original state). Test results, along with other results from literatures, will be used to classify types of utilization of fly ash concrete.

For this test, there are 5 specimens for each mix for statistical sufficiency. The dimension is 5 cm x 5 cm x 5 cm cubic. There will be the total of 20 mixes (100 specimens) tested for compressive strength. Five control mixes or 20 specimens (ones with no fly ash) will also be tested. Details on the proportions of mixes, with varying parameters, tested for compressive strength are as shown below:

- | | | | |
|------------------------------|-------------------|-----------|-----------|
| 1. Fly ash replacement (FA): | 0, 15, 30, 45, 60 | (percent) | (5 mixes) |
| 2. Age (A) (compressive): | 7, 28, 60, 90 | (days) | (4 mixes) |

Note: other parameters are held constant.

Leaching Test (adapted from EPA TCLP)

The objective of conducting leaching test for fly ash-cement mortars is to determine their leachate concentrations. Two sets of concentrations will be measured. First, the normal procedure requires grinding and digesting mortars as a preparation step. The concentrations measured are the extreme concentrations one may possibly expose to. Secondly, with all other parameters held fixed, fly ash mortars cubes with varying percent of cement replacement will be fully submerged into distilled water.

Concentrations of total arsenic will be determined by Graphite Furnace Atomic Absorption Spectrophotometry. For each mix, three specimens will be cast and tested for leaching. The total number of specimens is 60. The mixes, tested for leaching of arsenic contain the following variation:

- | | | | |
|------------------------------|-------------------|-----------|-----------|
| 1. Fly ash replacement (FA): | 0, 15, 30, 45, 60 | (percent) | (5 mixes) |
| 2. Age (A) (leaching): | 7, 28, 60, 90 | (days) | (4 mixes) |

Summary of Compressive Strength and Leaching Tests Schedule is tabulated in Table 3.5 to Table 3.8 below :

Phase 1: Casting Schedule, Age (A) = 90 days, tested for compressive strength and leaching. (C, L)

Table 3.4: Casting Schedule for cement-fly ash mortars at 90 days.

Mix ID	Weight	Proportion	Cement	Fly Ash	Sand	Water	Total	Factor
A90CL	W50	FA00	1	0	3	0.50	4.50	22.222
		FA15	0.85	0.15	3	0.50	4.50	22.222
		FA30	0.70	0.30	3	0.50	4.50	22.222
		FA45	0.55	0.45	3	0.50	4.50	22.222
		FA60	0.40	0.60	3	0.50	4.50	22.222

Phase 2: Casting Schedule, Age (A) = 60 days, tested for compressive strength and leaching. (C, L)

Table 3.5: Casting Schedule for cement-fly ash mortars at 60 days.

Mix ID	Weight	Proportion	Cement	Fly Ash	Sand	Water	Total	Factor
A60CL	W50	FA00	1	0	3	0.50	4.50	22.222
		FA15	0.85	0.15	3	0.50	4.50	22.222
		FA30	0.70	0.30	3	0.50	4.50	22.222
		FA45	0.55	0.45	3	0.50	4.50	22.222
		FA60	0.40	0.60	3	0.50	4.50	22.222

Phase 3: Casting Schedule, Age (A) = 28 days, tested for compressive strength and leaching. (C, L)

Table 3.6: Casting Schedule for cement-fly ash mortars at 28 days.

Mix ID	Weight	Proportion	Cement	Fly Ash	Sand	Water	Total	Factor
A28CL	W50	FA00	1	0	3	0.50	4.50	22.222
		FA15	0.85	0.15	3	0.50	4.50	22.222
		FA30	0.70	0.30	3	0.50	4.50	22.222
		FA45	0.55	0.45	3	0.50	4.50	22.222
		FA60	0.40	0.60	3	0.50	4.50	22.222

Phase 4: Casting Schedule, Age (A) = 7 days, tested for compressive strength and leaching. (C, L)

Table 3.7: Casting Schedule for cement-fly ash mortars at 7 days.

Mix ID	Weight	Proportion	Cement	Fly Ash	Sand	Water	Total	Factor
A7CL	W50	FA00	1	0	3	0.50	4.50	22.222
		FA15	0.85	0.15	3	0.50	4.50	22.222
		FA30	0.70	0.30	3	0.50	4.50	22.222
		FA45	0.55	0.45	3	0.50	4.50	22.222
		FA60	0.40	0.60	3	0.50	4.50	22.222

Overall Testing Schedule (C, L): 7-28-60-90 days

3.3 Process Analysis

3.3.1 Verification and Sensitivity Analysis

Verification of risk assessment process will be done in part using RISK*ASSISTANT software package by inputting as much the same data as manual assessment as possible, for one case of certain population group of a scenario. Some inputs may need modification as the best estimation. Results from RISK*ASSISTANT will be compared to those obtained from previous evaluation. Similar results are expected. Sensitivity analysis will be done partly by RISK*ASSISTANT and mostly by spreadsheet functions after valid verification from the previous step.

3.3.2 Comparative Analysis

This step of analysis will lead to an achievement of the third objective of the Study. This step compares the results from two scenarios: overall resultant risk from fly ash for storing fly ash, and overall risk for utilizing fly ash as concentration materials (both present and potential utilization).

3.4 Result Implementation

After comparative analysis, this step recommends how to apply the resultant risks to the decision making process. This step will lead to suggestion on fly ash utilization and/or remediation/treatment. In other words, this step will suggest how this assessment tool and evaluation could practically be applied to actual site-specific situations.

3.5 Working schedule

Preliminary data were collected in advance and throughout the study. The site visits took places many times during November 2001 and August 2003. The site survey and data collection was in July 2002. The laboratory work period was from July to December 2002. The population interview was completed during 10 – 17 April 2003. The data analysis and evaluation phase began in September 2002 to September 2003.

CHAPTER IV

RESULTS

4.1 Introduction

In Chapter 3, methods and methodologies for the overall study were explained. This Chapter provides the results of steps described earlier in the order of risk assessment procedure to facilitate the understanding of complicated assessment processes. The results are presented in the following order: complete exposure pathways, exposure assessment, quantification of exposure, calculation of cancer risks, modeling of risk contribution, summary of cancer risks, and the results of RISK*ASSISTANT.

4.2 Complete Exposure Pathways:

By completing a preliminary survey, an extensive site survey, interviews and reviewing related documents, complete exposure pathways for the Mae Moh plant can be drawn as shown in the next page:

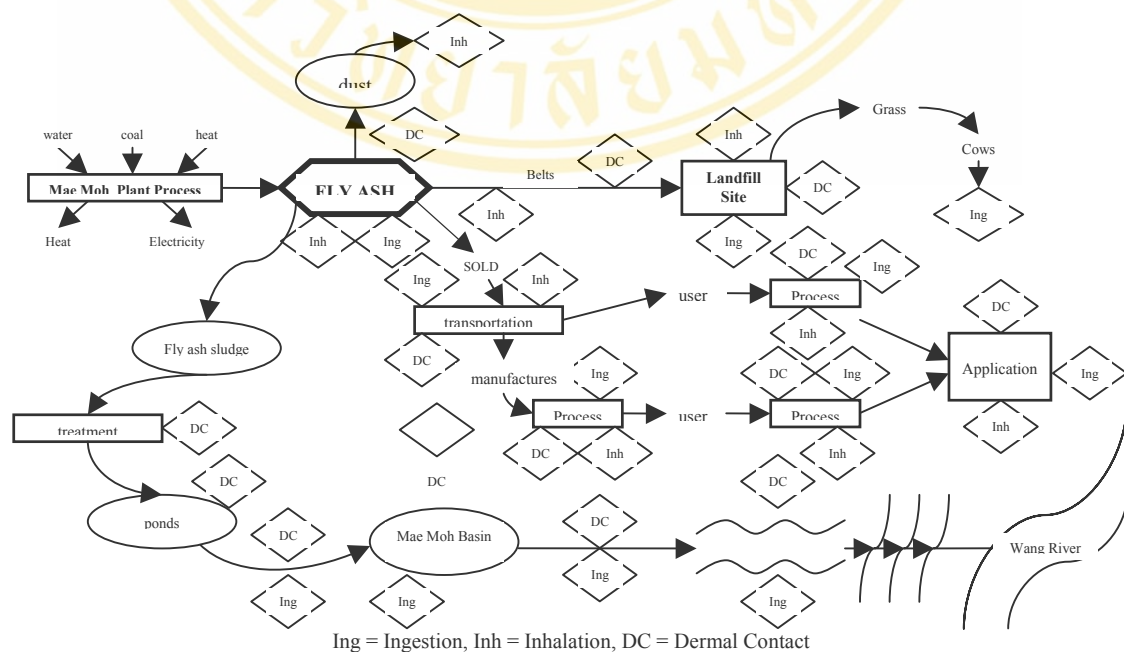


Figure 4.1: Complete Exposure Pathways of Human Health Risk Assessment.

All possible complete exposure pathways to arsenic are presented in the Figure shown above. 'Ing' represents ingestion pathway, 'Inh' represents inhalation pathway, and 'DC' represents dermal contact pathway. Fly ash can be stored and/or sold as depicted above, while some portion of fly ash at the plant has to be treated by existing ash water treatment system before discharging to natural water.

The storage of fly ash may involve human health risk from the operation at the plant, along the route of transportation to the site, and at the storage site itself. Workers, local villagers and visitors are subject to such risk. There will be no risks for utilization population in this case, however storing fly ash results in some risks for residential population. This is due to the fact that there is some amount of fly ash that has to be treated by the water treatment system, although most of fly ash is transported through belt conveyors up to storage or disposal sites.

The process involving selling of fly ash may involve human health risk from the operation at the plant, along the route of transportation to the destination, and at the destination, which depends on the resulting types of utilization. Workers, drivers, and users of fly ash incorporated products are subject to possible risk. Similarly, residential population living along the river may expose to health risk associated with this option. Although, most of fly ash is transported to other destinations, some fly ash has to be treated by the water treatment system.

In both cases, some amount of fly ash at plant's units (4-13) will be treated through the (ash) water treatment system, consisting of series of ponds. After this system, the treated water is discharged into natural water, in this case, Mae Chang River. Residual arsenic in the water may cause additional risk to local villagers living downstream. A model is used to approximate arsenic concentrations in water for both cases.

SENARIO 1: Complete Storage of Fly Ash

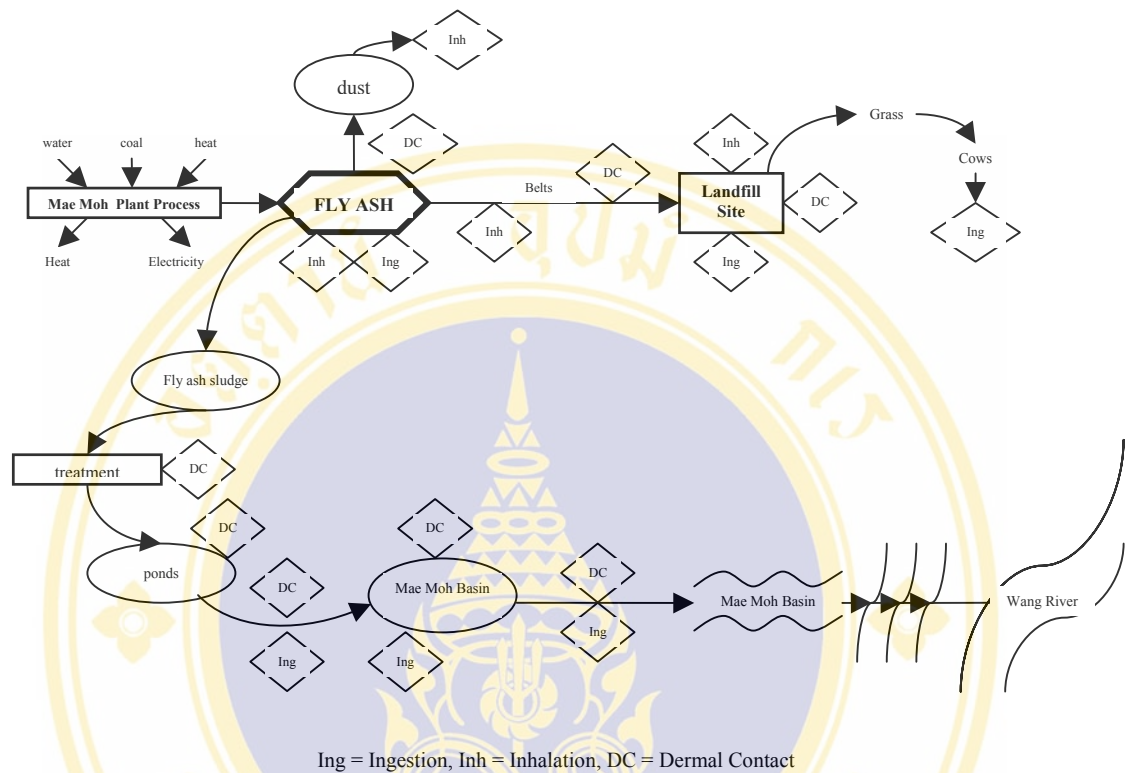
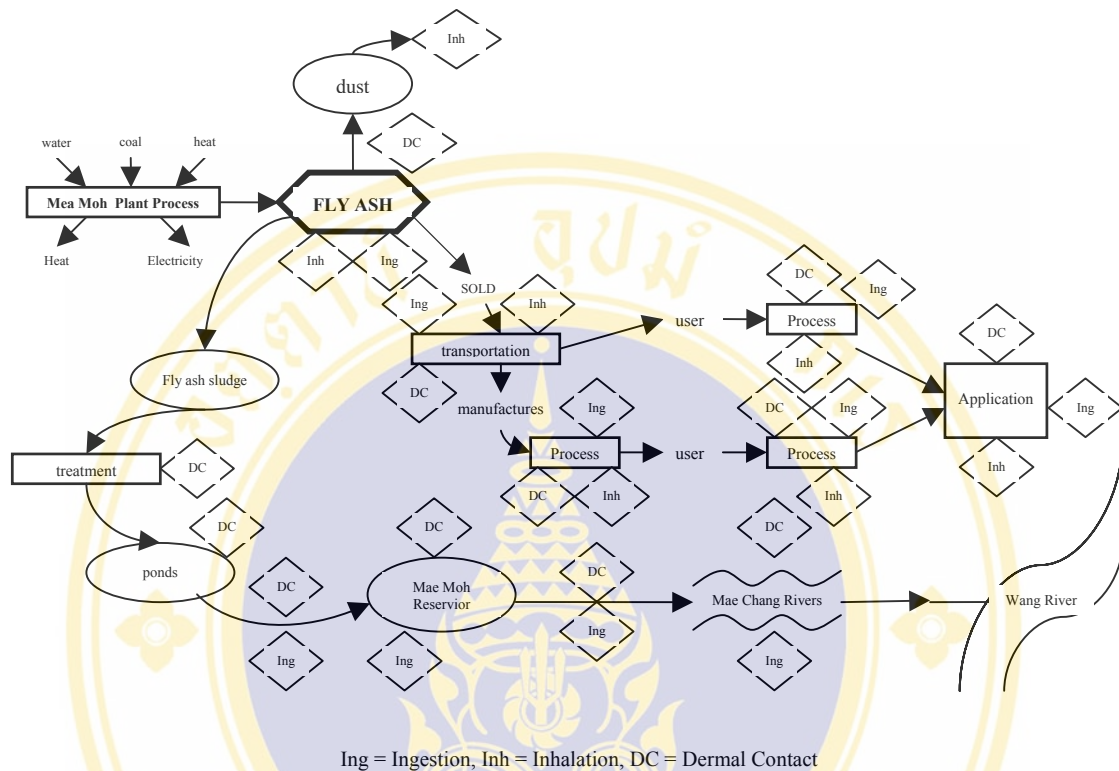


Figure 4.2 : Exposure Pathways for Complete Storage of Fly Ash

Storing fly ash as depicted by Figure 4.2 involves many routes of exposure at different sites. At the plant itself (units 4 – 13), workers are subject to incidental ingestion, inhalation, and dermal contact of fly ash. Along the belt conveyors, worker and visitors are subject to ingestion and dermal contact, while at the disposal site, workers and visitors may expose to fly ash via ingestion, inhalation and dermal contact. A portion of fly ash is treated by the treatment system as shown in Figure 4.4. Workers and local villagers may be exposed to arsenic via ingestion and dermal contact via river water with some concentrations of arsenic.

SCENARIO 2: Complete Sale of Fly Ash**Figure 4.3: Exposure Pathways for Utilizing Fly Ash as Construction Materials**

According to the Engineering Institute of Thailand specification , ISBN 974-89517-2-3, EIT Standard 1014-40, 1998, fly ash is a type of mineral admixtures used for special purposes such as heat and water reduction, prevention of shrinkage, etc.

Infrastructure of the Mae Moh plant has recently been modified so that trucks can drive to reach at loading points for the purpose of maximizing the sales amount. All machine units, at present, are capable of selling fly ash. However, the electricity process is non-stop and as a result fly ash is continuously produced. When the quality of fly ash produced does not meet the requirements for sales, fly ash will be belted to the storage site. The recent amount of fly ash sales and a list of buyers are shown in Appendix A.

Figure 4.3 shows potential exposure pathways for completely utilizing fly ash as construction materials. People can be exposed to arsenic in fly ash along the process of production at the plant, transportation to manufactures and to end-users. Local people downstream are also exposed to residual arsenic from treated water that

is discharged to the river. Extrapolated concentrations of arsenic in the river are linearly modeled to determine human health risk.

4.3 Exposure Assessment

4.3.1 Source Generation

Ten units of power generating systems at the Electricity Generating Authority of Thailand, Mae Moh mine can produce 2,400 mega Watts of electricity, the second highest in Thailand. The electricity is distributed to provinces in the north (50%), the central region (30%), and the northeast (20%) (EGAT, 2001).

Each day approximately 45,000 tons of coal is used as input of the electricity generating process. Nine thousand tons of fly ash is produced daily. Units 4 – 7 each have maximum production of 600 tons a day, while units 8 – 13 each can produce up to 1,100 tons a day. (Ponlit, 2003)

According to Nimityongskul and Sayamipak, 2000, lignite coal is brown to dark brown in color, with relatively low quantity of carbon and high moisture content compared to other types of coal (bituminous and anthracite). It is the lowest quality of natural coal. In the process of generating electricity, lignite is ground, burned for heat. The remaining of burning, fly ash, will float with heated gas, collected by electrostatic precipitator and stored in ash hopper. Average diameter of fly ash is 1 – 150 microns.

The By-products Management Section regularly take four samples of fly ash are taken daily to ensure it meets ASTM C-311 standard with:

- Maximum Sulfur Trioxide 4.0 %
- Maximum Free CaO 2.0 %

(By-product Management Section, 2001)

Mae Moh fly ash is found to meet ASTM C 618-94a (1995) Class C with the following criteria: (Nimityongskul and Sayamipak, 2000)

As a standard practice at the Mae Moh plant following an SO₂ emission incident in 1992, raw coal should not have more greater than 5% of Sulfur to prevent possible air pollution. When the Sulfur content is relatively high, a portion of it will be mixed with low-sulfur coal to make an average acceptable content. The practice is even more stringent in winter when the weather is cooler and the air is more stagnant. (Pakowong, 2001).

Sulfur trioxide percentage in fly ash is critical to its utilization. The high sulfur trioxide content retards the hardening and casting process and leads to lower compressive strength of concrete. The content of SO_3 in fly ash should be small with general acceptant limit of about 3 – 4%.

Yearly averages of fly ash composition, including SO_3 and other substances, during 1990 – 1998 are shown in the Table 4.1 below: (Jaturapitak et al., 1999)

Table 4.1: Chemical Composition of Mae Moh Fly Ash from 1990 – 1998

Chemical Composition	Average Percent by Weight								
	2533	2534	2535	2536	2537	2538	2539	2540	2541
SiO_2	37.8	42.8	40.3	43.1	52.8	40.6	40.6	41.5	37.3
Al_2O_3	20.5	23.3	24	20.2	18	22.8	23.6	28.1	22.1
Fe_2O_3	14.2	14	15	13.2	8.5	12.8	13	12.3	14.4
CaO	17.4	10.5	11.2	13	13.3	14.4	13	10	11.4
SO_3	3.9	3.9	3.1	2.6	2.8	2.8	2.4	2	2.5
MgO	3.3	2.4	2.8	2.7	1.4	2.5	2.5	1.2	2.7
Na_2O	0.9	0.8	1	1.3	0.9	0.7	1.2	0.6	1.1
K_2O	2.1	2.3	2.6	2.4	2	2	3	3.3	2.7
Loss on Ignition	0.8	0.7	0.5	0.6	0.3	0.9	0.7	0.8	0.1

Loss on ignition is defined by the percentage of energy loss in heating to start up the process by igniting coal up to a temperature it can yield energy.

While fly ash properties in 1999 are summarized in Table 4.2 below: (By-production Management Section, 2001)

Table 4.2: Mae Moh Fly Ash Properties in 1999

%	LOI	SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	Na_2O	K_2O	P_2O_5	SO_3
MAX	0.42	59.72	29.34	0.62	16.58	18.68	5.36	2.06	3.45	0.51	3.82
MIN	0	31.11	16.02	0.39	5.56	3.99	1.05	0.24	2.12	0.02	0.28
AVG	0.09	39.92	23.81	0.49	12.65	10.52	2.89	1.27	3.08	0.15	1.83
SD	0.13	3.55	2.21	0.03	1.45	2.18	0.76	0.28	0.21	0.06	0.54

Table 4.1 and Table 4.2 show the tendency of consistent decrease in SO₃ content in Mae Moh fly ash. This tendency benefits the possibility of utilizing fly ash in construction business as shown by a consistent increase in fly ash sale by the By-product Management Section, EGAT (EGAT, 2001 and EGAT, 2003).

4.3.2 Environmental Transport and Exposure Analysis

After it is collected by electrostatic precipitator, fly ash is transported by belt conveyors to the dumping sites, locating a few kilometers north up in the valley. Water spraying at the belts and the roads up to the valley is used to prevent dust. Some amount of fly ash is sold and transported by trucks to many destinations in all regions of Thailand. As shown in the chart, different routes of exposure can occur; ingestion, inhalation, and dermal contact. Assessment of human health risk depends on many variables, including those of sources, pathways, and receptors, as discussed earlier. Risk depends on type of utilization, therefore wise use of fly ash is preferred.

Possible Complete Pathways for Residential Population (for both scenarios):

- Ingestion (drinking, brushing teeth, etc.)
- Ingestion (eating fish)
- Dermal Contact (swimming)
- Dermal Contact (farming)

Possible Complete Pathways for Occupational Population (for both scenarios):

- Inhalation (arsenic particulates)
- Ingestion (incidental)
- Dermal Contact (fly ash)

4.3.3 Population Determination

According to the site model and the results from experimental investigation, people who are 'at some degree of risk' for arsenic are local villagers in some area of Mae Moh district, Mae The district, and Koa Ka district of Lampang province, as well as workers at the Electricity Generating Authority of Thailand, Mae Moh site and visitors from different places.

Exposure Population for each scenario can be summarized on the next page:

Current Fly Ash Storage and Sale:

- Occupational Groups (Workers at Plants and Storage Site and visitors)
- Residential Group (Living along the River)
- Utilization Group (Drivers, Workers at Ready Mixed Concrete Plant, and End Users)

Scenario I: Complete Fly Ash Storage:

- Occupational Groups (Workers at Plants and Storage Site)
- Residential Group (Living along the River)

Scenario II: Complete Fly Ash Sale:

- Occupational Groups (Workers at Plants and visitors)
- Residential Group (Living along the River)
- Utilization Group (Drivers, Workers at Ready Mixed Concrete Plant, and End Users)

4.3.3.1 Workers at EGAT:

A number of workers are hired to work for EGAT. These people who face some risk include workers at the storage site, and in an area nearby plant units 4 – 13. Number of workers, concentration of arsenic in each medium that result in a route of exposure, and estimated time of exposure are required to estimate the overall human health risk for workers. These people can potentially be exposed to inhalation of particulates, incidental ingestion, and dermal contact.

Workers at plant units 4 – 13 are divided into 3 shifts a day, morning, afternoon, and night shifts, 8 hours per shift. One person is responsible for each unit, therefore there are 10 people in a shift. After a night shift, workers are allowed one day off duty. Additional 30 days of vacation are allowed per year, however some of workers may not take their vacation and some may take vacation and still stay in EGAT vicinity. This of workers are exposed to higher risk than others.

Workers at storage site, approximately 10 at a time, are on duty during 8:30 a.m. to 4:30 p.m. for 10 days and will have 5 days off duty. Additional vacation of 30 days per year is also authorized.

4.3.3.2 Visitors:

Approximate number of EGAT's visitors who may be at risk and location of visit, as well as the duration are obtained from the EGAT's Public Relation Section. Visitors may spend time at the public relation building for presentation, in a vehicle for a site visit, sometimes to the plant to observe the operations, and once in a while to the storage site. This information will be useful for overall assessment of risk for visitors.

Information on occupational population including workers and visitors can be summarized in the Table 4.3.

Table 4.3: Summary of Description and Possible Complete Pathways for Occupational Population (Workers and Visitors)

Receptors	Description	Possible Complete Pathways		
		Inhalation	Incidental Ingestion	Dermal Contact
Workers at plants # 4 – 13	Work in shifts for 8 hours each, and additional 30 days of vacation/year	All workers 5/7 days avg	Yes	Yes
Workers at Storage Site	Work 10 days and take 5 days off, all year round, and up to 30 days of additional vacation/year	All workers 10/15 days avg	Yes	Yes
Visitors	Visit different sites: plants and storage site. Information from public Relation Office	Proportional to conc. and time spent	Yes	Yes

4.3.3.3 Utilization Group

Utilization population (or group) are those who may be exposed to arsenic in types of utilization, and thus may result in some degree of cancer risks. There are 3 primary types of utilizers of ready mixed concrete products, namely:

1) General Building Structures: ready mixed concrete is used to build different structures such as floor, beams, and columns. These types of utilization usually consist of 20 – 30 percent of fly ash in concrete.

2) Road Surface: many road surfaces are currently using ready mixed concrete with a portion of fly ash from 10 – 15 percent. The cost of construction is lowered

while gaining desirable properties such as cracks prevention. More amount of fly ash will retard the casting process and is not practical.

3) Special Purpose Structures: structures such as dams and large foundations require low heat of hydration process. Fly ash is utilized in large proportion, up to 50 to 60 percent, in these types of structures.

For all types of users, most exposed populations are considered to be truck drivers, and construction workers for road and structure constructions. This is due to the fact that the truck drivers are exposed to inhalation and dermal contact of fly ash during transportation and the nature construction works where workers have to be exposed to fly ash and mixed concrete via dermal contact and inhalation.

4.3.3.4 Local villagers (Residential Group):

Local villagers are subject to risk from EGAT, primarily through ingestion and dermal contact of river water, especially the Mae Chang Rivers, which runs from Mae Chang Reservoir, through EGAT (used as plant input), Mae Moh Reservoir, through Mae Moh district, Mae Tha district, and reaches the Wang River in Koa Ka district of Lampang province. The number of people in each village, classified by age and gender, is shown in Appendix C.

A pattern of water consumption depends on peoples' way of living: what they do for living, how much and how often they drink water, brush teeth, take bath, etc. For this reason, water consumption pattern and rates for each village were determined by approximation of a village leader and his/her assistant, through extensive interview. People who drink from Mae Chang River were interviewed due to possible higher risks. More details are attached in Appendix D. Information on number of population classified by age by each village was acquired from the local sanitary department organization that performs regular head counts or yearly census. Assumptions of local villagers (residential population) include:

Age 0 – 1 year	Stay home with parents, grandparents or relative, possibly exposed to ingestion (drinking water) and dermal contact (showering)
----------------	---

Age 1 – 4 year	Stay home and go with parents to farm, possibly exposed to ingestion (water, fish) and dermal contact (swimming, farming, showering)
Age 5 – 14 year	Go to schools during weekdays, stay home or go to farms with parents during weekends, possibly exposed to ingestion (water and fish) and dermal contact (swimming, farming, showering)
Age 15 – 59 year	Work during weekdays and weekends for farmers, others work during weekdays, stay home during weekends, possibly exposed to ingestion (water and fish) and dermal contact (swimming, farming, showering)
Age 60 and over	Retire and stay home, possibly exposed to ingestion (water and fish) and dermal contact (swimming, farming, showering)

All children, between 5 – 14 years of age, are assumed to go to school during weekdays for 8 hours a day (8 am – 4 pm). Figure 4.5 shows approximate locations of these schools. Numbers 1 – 5 in circles indicate background locations. In addition, the stars designate locations of villages that drink from the Mae Chang River.

A survey of local schools found that all students, teachers, and other employees do not drink river water:

- A) EGAT Mae Moh Withayanukroh
- B) Ban Hang Hung School
- C) Ban Mae Moh Withayakom School
- D) Mae Moh Station School
- E) Ban Pa Meaw School
- F) Ban Mae Lu School
- G) Ban Hua Sua School
- H) Ban Kom School
- I) Mae Tha Prachasamakee School
- J) Mae Tha Withaya School
- K) Ban Nong Luang School
- L) Ban Nam Thong Community School
- M) Ban Na Kwao School

- N) Ban Na Kwao Kew School
 O) Ban Nong Thoi School
 P) Ban Na Krua Prachasamakee School
 Q) Ban Pa Tan School
 R) Ban Nong School
 S) Ban To School

Residential Population Exposure Characteristics by Village are shown in Table 4.4:

Table 4.4: Residential Population Exposure Characteristics by Village

Village/District	Population	# House Holds	Drink Water?	Other Uses?	Swim?	Cosume Fish?	Fish Culture?	Farming/ Plantation?
Hang Hung/Mae Moh	1133	254	No	Yes	No	Yes	No	Yes
Station/Mae Moh	721	227	Yes	Yes	Yes	Yes	Yes	Yes
Kom/Mae Tha	536	139	Yes	Yes	Yes	Yes	No	Yes
Hua Sua/Mae Tha	1038	321	Yes	Yes	Yes	Yes	No	Yes
Don Mun/Mae Tha	578	147	No	Yes	Yes	Yes	No	Yes
Mae Lu/Mae Tha	1040	262	Yes	Yes	No	Yes	No	Yes
Sop Rai/Mae Tha	279	69	No	Yes	Yes	Yes	No	Yes
Ban Mail/Mae Tha	695	179	No	Yes	Yes	Yes	No	Yes
Ban Mai8/Mae Tha	640	161	No	Yes	Yes	Yes	No	Yes
Pong Pa Pao/Mae Tha	696	165	No	Yes	Yes	Yes	No	Yes
Sop Po/Mae Tha	247	68	No	Yes	Yes	Yes	No	Yes
Nam Thong/Mae Tha	1594	372	No	Yes	Yes	Yes	Yes	Yes
Ban Luk/Mae Tha	1127	248	No	Yes	Yes	Yes	Yes	Yes
Nong Thoi/Mae Tha	921	224	No	Yes	Yes	Yes	No	Yes
Ban Hom/Mae Tha	557	270	No	Yes	No	Yes	No	Yes
Ban Lug Tai/Mae Tha	725	178	No	Yes	Yes	Yes	Yes	Yes
Na Kwao/Mae Tha	752	172	No	Yes	Yes	Yes	Yes	Yes
Ban Pao/Mae Tha	1027	245	No	Yes	Yes	Yes	No	Yes
Ban Na Khot/Mae Tha	1206	306	No	Yes	Yes	Yes	No	Yes
Pa Tan Nua/Mae Tha	1010	251	No	Yes	Yes	Yes	No	Yes
Pa Tan Tai/Mae Tha	1449	336	No	Yes	Yes	Yes	No	Yes
Sop Tha/Mae Tha	394	88	No	Yes	Yes	Yes	Yes	Yes
Ban To/Mae Tha	1738	428	No	Yes	No	Yes	No	Yes
Ban Nong4/Mae Tha	1210	276	No	Yes	Yes	Yes	No	Yes
Ban Nong9/Mae Tha	838	202	No	Yes	Yes	Yes	No	Yes
Wang Phrao/Koa Kha	996	224	No	Yes	Yes	Yes	No	Yes
Sop Chang/Koa Kha	1012	278	No	Yes	Yes	Yes	No	Yes

4.3.4 Total Arsenic Concentration Determination

Samples of consumed river water were taken and analyzed for concentration of total arsenic and summarized, in the order of the villages along the direction of the flow of Mae Chang River, in the Table 4.5.

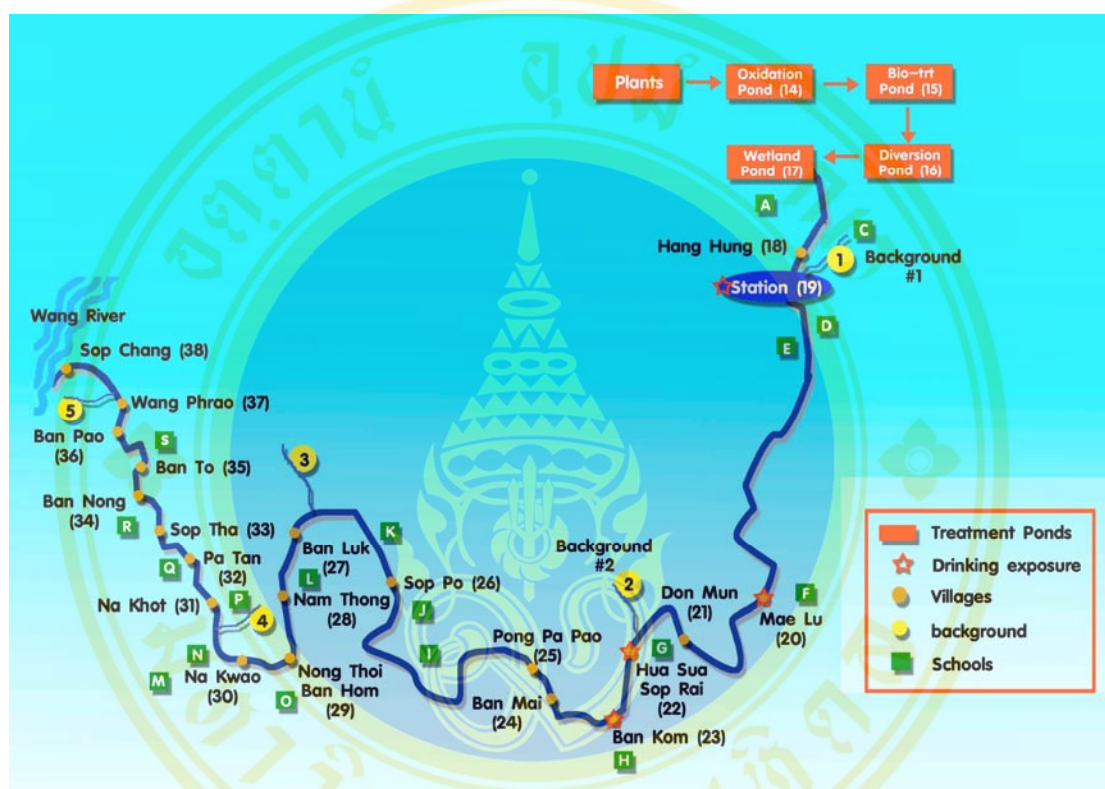


Figure 4.4: Approximate Locations of Treatment Ponds, Schools, and Villages downstream of Plant, along the Mae Chang River

Table 4.5: Information of Sampling Points for Determination of Arsenic Concentration

Sample Number	Representing Medium and Villages/Location	Distance from Plant to Sampling Points (km)	Direction from Plants to Sampling Points	Distance from Discharge to Sampling points (km)	Avg As Conc (ppb)
1	Fly ash (plants 4- 13)	0	-	-	322000
2	Fly ash (along conveyor)	1 – 3	N	-	278000
3	Fly ash (storage site)	4	N	-	298000
4	Ash water lake	1	S	-	25000
5	Plant Species 1 (root) storage site	4	N	-	6670
6	Plant Species 2 (leaf) storage site	4	N	-	7560

7	Plant Species 2 (flower) storage site	4	N	-	6870
8	Plant Species 3 (leaf) storage site	4	N	-	3790
9	Plant Species 4 (leaf) storage site	4	N	-	3890
10	Plant Species 5 (leaf) storage site	4	N	-	1510
11	Plant Species 6 (leaf) Hang Hung	3	S70°W	-	6750
12	Plant Species 6 (root) Hang Hung	3	S70°W	-	7240
13	Plant Species 7 (leaf) Nam Thong	29	S52.5°W	-	8780
14	Oxidation pond	2	W	-	553
15	Bio-treatment pond	3	W	-	123
16	Diversion pond	5	SW	-	95
17	Wetland pond	8	SW	-	53
18	Hang Hung	3	S70°W	-	32.8
19	Mae Moh Station	6.5	S55°W	0	28.7
20	Mae Lu	13.5	S35°W	14.5	13.4
21	Don Mun	17	S30°W	19.5	14.6
22	Hua Sua/Sop Rai	19	S35°W	24	12.4
23	Ban Kom	20.5	S35°W	28.5	10.3
24	Ban Mai1/Ban Mai8	26.75	S42.5°W	31	11.5
25	Pong Pa Pao	23	S37.5°W	33	9.0
26	Sop Po	26.5	S50°W	43.5	8.5
27	Luk/Luk Tai	30	S52.5°W	48	10.1
28	Nam Thong	29	S52.5°W	48.5	8.9
29	Nong Thoi/Ban Hom	33	S52.5°W	51	7.8
30	Na Kwao	33.5	S50°W	55.5	5.4
31	Na Khot	34	S55°W	59.5	6.2
32	Pa Tan Nua/Pa Tan Tai	35	S55°W	61	7.1
33	Sop Tha	34.5	S60°W	63	6.4
34	Ban Nong 4/Ban Nong 9	37	S60°W	67.5	6.6
35	Ban To	37.5	S62.5°W	71	3.5
36	Ban Pao	39	S62.5°W	73.5	2.4
37	Wang Phrao	41	S65°W	77.5	2.0
38	Sop Chang	42.5	S67.5°W	81	1.3

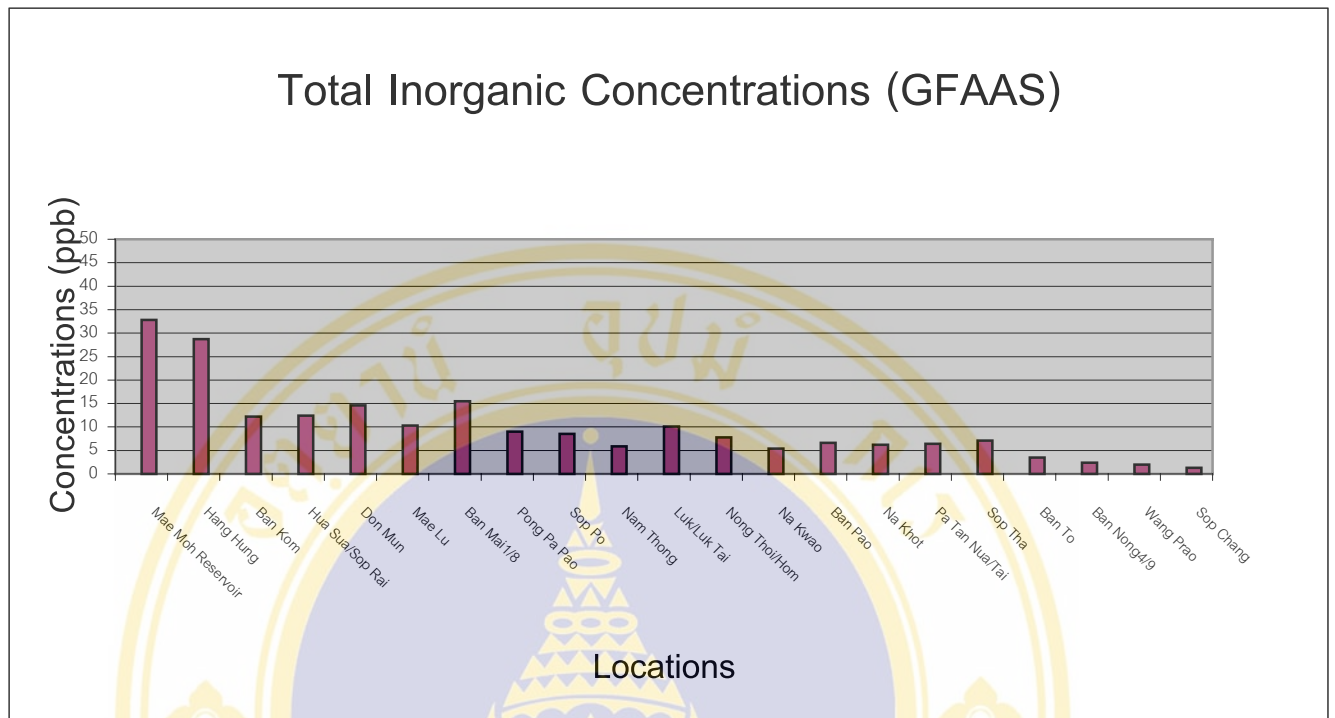


Figure 4.5: Plot of Total Arsenic Concentration by Village

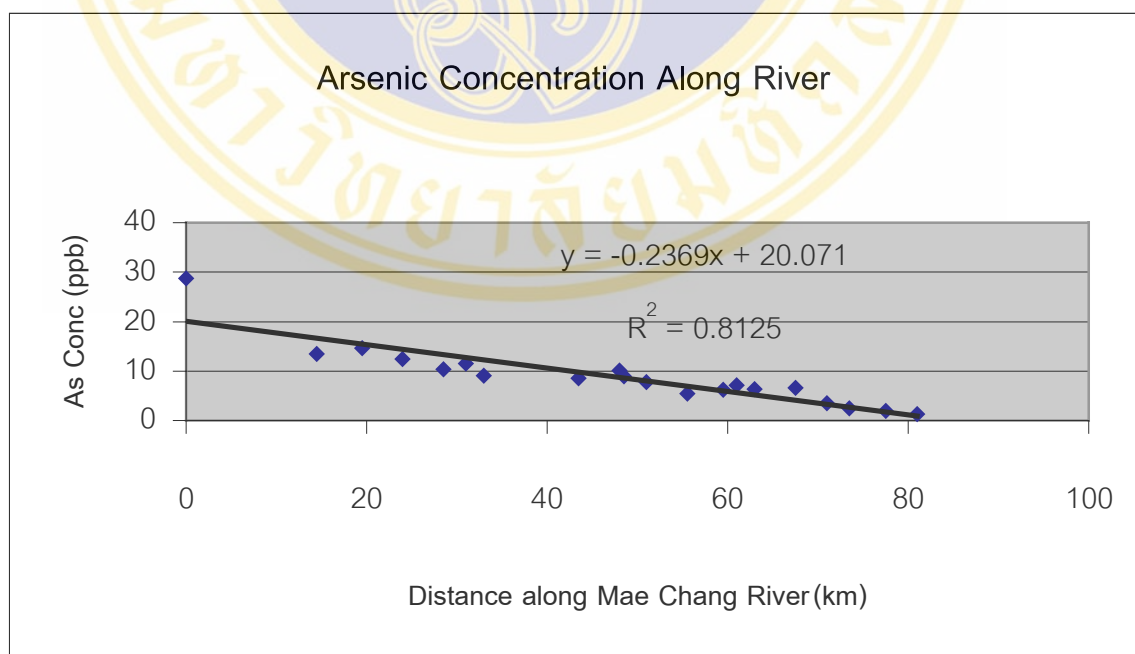


Figure 4.6: Arsenic Concentration vs Distance along the Mae Chang River

Background Concentrations

Based on topographic and geological information, background points are selected to represent a group of villages. Samples for background are taken from natural rivers in that area that do not have an influence from Mae Chang River, i.e. water runs from these points to Mae Chang River due to their higher elevations.

Table 4.6: Background Arsenic Concentration in the Mae Chang River

Location	Representing Villages	Arsenic Concentration
1 Hang Hung	Hang Hung/Mae Moh Station	2.6 ppb
2 Hua Sua	Ban Kom/Hua Sua/Don Mun/Mae Lu/Sop Rai	4.4 ppb
3 Ban Luk Nua	Ban Mai1/Ban Mai8/Pong Pa Poa/Sop Po/Nam Thong/ Luk Nua /Luk Tai/ Nong Thoi/Ban Hom	4.7 ppb
4 Na Khot	Na Kwao/Ban Bom/Na Khot/Pa Tan Nua/Pa Tan Tai/Sop Tha/Ban To/Ban Nong4/ Ban Nong9	2.2 ppb
5 Wang Phrao	Wang Phrao/Sop Chang	1.5 ppb

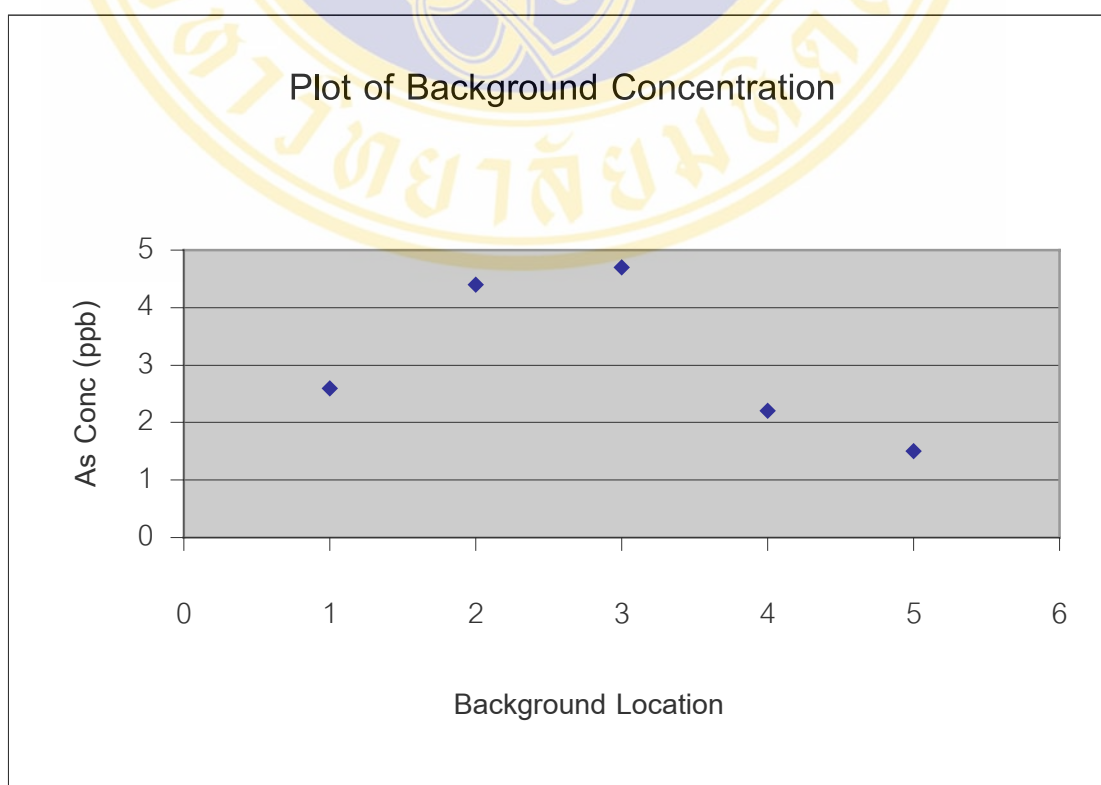


Figure 4.7: Plot of Arsenic Concentration of Background Points 1 - 5

4.3.5 Dust Concentration (in Air) Measurement

(for inhalation exposure of occupational population):

Information on air concentration of the plant is responsible by the Occupational Safety Section, which keeps record of air concentrations available since January 2002. This information, although not based on many statistical points, helps create a model to predict concentrations of treated water discharged to the natural river. This information is shown in Appendix E. Dust concentration in air around storage sites has not been monitored by any organization or agency. To evaluate human health risk due to inhalation exposure, expert opinion will be used to estimate the dust concentration.

An expert opinion of Thammarong (2003) and Pakowong (2003) approximated the dust concentration at the storage site to be roughly the same as that at the plant units. There are reasons for this estimation. Although the concentration at the storage site may seem to be higher than that of the plant unit due to the fact that the working place is an open area and the ash is dropped from a high elevation, however, all ash is sprayed with water to reduce a dispersion into the air. A typical average and reasonable maximum dust concentration from the plant units will be applied for the assessment for inhalation risk of workers at the storage site.

4.3.6 Concentration of Arsenic in Fish

Total arsenic concentrations in fish caught in the Mae Moh Reservoir were recorded by Department of Medical Science, Ministry of Public Health. The recorded number in August 1998 was 0.026 mg/kg and 0.052 mg/kg in May 2000 (EGAT, 2003). Out of total arsenic in fish, 1% is assumed to be inorganic (U.S. EPA, 1999). The concentration of arsenic in fish is also assumed to be linearly varied with concentration of arsenic in River water. For example, concentration of total arsenic in fish in Mae Moh Reservoir is assumed to be 0.00052 mg/kg fish, while concentration of total arsenic in fish in other villages will depend on the corresponding total arsenic concentration in each village along the river. All residential populations are assumed to each fishes that are caught locally or in their village.

4.3.7 Arsenic Concentration in Plant Species

In order to assess human health risk due to arsenic in plant species, types of plants were identified and concentrations of plants from the storage site and background concentrations were determined. The extensive site inspection showed that there were no edible plant species at the storage site and the concentrations of arsenic were tabulated in Table 4.5. The assessment further looked at grasses (species 1, 2, 3, 6, and 7) from storage site and other locations that were used as background. This is because grasses are the only types of plants on the storage site that can be eaten by cows and a portion of arsenic in grasses may pass on to cows and finally to people who eat cow meat (there were only meat cows in EGAT open area)

However, after a consideration, it was found that this pathway is not of additional risks and therefore was not further assessed. Many reasons supported the decision. First, concentrations of arsenic measured from grasses at the storage site were not different from those measured from background locations. These grasses were not arsenic accumulators because concentrations of arsenic in plants, both root and leaf, are much lower than those of fly ash. Second, it is not likely that cows would eat grasses at the storage site because of its high elevation and relative infertility. There are other open fertile open area with lower elevation and closer to access roadways that are more suitable for raising cows. Third, arsenic from grasses will be transformed to organic arsenic, which is much less toxic to humans.

In addition, information from interview showed that most cows will be sold to many markets, mainly Amphur Muang of Lampang province, which is out of the study area, according to other exposure pathways. Further, the process of determining arsenic concentration in cow meat is complicated, expensive, and time consuming. Collecting cow meat samples would pose a contradiction with the sample collection consideration criteria, given that the result would yield minimal contribution to the overall risks.

Risk assessment of utilization population requires information from leaching test and compressive strength test as discussed in Chapter 3.

4.3.8 Leaching Test

A determination of total arsenic concentration by leaching test was done at 28 days after casting, at different percentage of fly ash. Submerged water and crushed fly ash-cement mortars were analyzed for total arsenic concentrations. Submerged water for each mortar with different percentage of fly ash was directly analyzed without digestion.

The concentrations determined were typical average in the risk assessment. However, the maximum possible leaching concentrations were measured from crushed samples of mortars with different percentage of fly ash. These samples had to be digested as a preparation step before the measurement by Graphite Furnace Atomic Absorption Spectrophotometry. Details were given in section 3.2.2.

The results of the leaching tests are tabulated below:

Table 4.7: Average Total Arsenic Concentrations (submerged and crushed) for different Percent Fly Ash in Mortars

Percent Fly Ash	Average Concentration (Submerged Water)	Average Concentration (Crushed Mortars)
0%	No detection	29.1 ppb
15%	No detection	33.3 ppb
30%	No detection	43.7 ppb
45%	1.2 ppb	57.8 ppb
60%	2.1 ppb	79.2 ppb

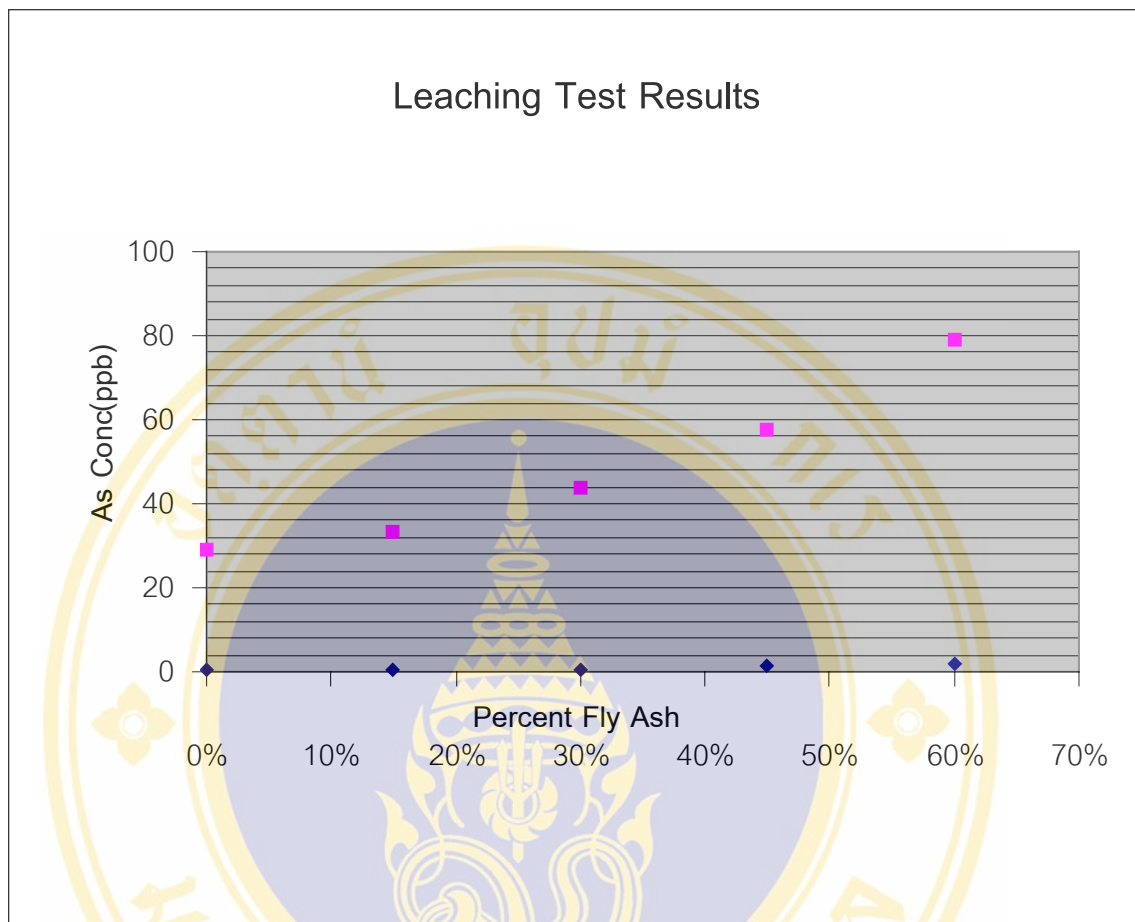


Figure 4.8: Plot of Leaching Test Results at Different Percentages of Fly Ash in Mortars

The results from leaching test, graphically shown in Figure 4.8, show the expected tendency of arsenic leaching from fly ash-cement mortars. At 0% fly ash or the background/controlled mix, no arsenic was detected in submerged water, but some amount was detected and used as background concentration. At low percentage of fly ash mixture, i.e., up to 30%, no arsenic was detected in submerged water.

Higher total arsenic concentration was found with higher amount of fly ash in mortars, for both submerged water and crushed samples. Note that the national standard for drinking water for arsenic is 50 ppb. For no detection, one half the detection limit or 0.5 ppb is used for conventional risk assessment.

4.3.9 Compressive Strength Tests

The result of compressive strength test, according to testing schedule is summarized in Tables below:

Table 4.8: Results of Compressive Strength Test at 7 days

7 days								
Date of experiment: 15 August 2002								
%F.A / Exp no.	1		2		3		Average	
	(ton)	(ksc)	(ton)	(ksc)	(ton)	(ksc)	(ton)	(ksc)
0%	7.25	290	8.5	340	7	280	7.583	303.33
15%	4	160	5.25	210	6	240	5.083	203.33
30%	4	160	4	160	4.8	190	4.25	170
45%	3.5	140	3.8	152	3.8	150	3.683	147.33
60%	3	120	3.5	140	3.25	130	3.25	130

Table 4.9: Results of Compressive Strength Test at 28 days

28 days								
Date of experiment: 5 September 2002								
%F.A / Exp no.	1		2		3		Average	
	(ton)	(ksc)	(ton)	(ksc)	(ton)	(ksc)	(ton)	(ksc)
0%	7.8	312	8.7	348	8	320	8.167	326.67
15%	6.5	260	6.4	256	6.7	268	6.533	261.33
30%	5.2	208	6	240	6	240	5.733	229.33
45%	4.6	184	4.7	188	4.6	184	4.633	185.33
60%	4.2	168	4.4	176	4.2	168	4.267	170.67

Table 4.10: Results of Compressive Strength Test at 60 days

60 days								
Date of experiment: 16 September 2002								
%F.A / Exp no.	1		2		3		Average	
	(ton)	(ksc)	(ton)	(ksc)	(ton)	(ksc)	(ton)	(ksc)
0%	10.6	424	11.4	456	11	440	11	440
15%	9.8	392	9.9	396	10.2	408	9.967	398.67
30%	9.9	396	10	400	9.6	384	9.833	393.33
45%	8.5	340	8.5	340	8.1	324	8.367	334.67
60%	5.3	212	5.4	216	5.4	216	5.367	214.67

Table 4.11: Results of Compressive Strength Test at 90 days

90 days								
Date of experiment: 3 October 2002								
%F.A / Exp no.	1		2		3		Average	
	(ton)	(ksc)	(ton)	(ksc)	(ton)	(ksc)	(ton)	(ksc)
0%	11	440	10.6	424	11.6	464	11.067	442.67
15%	10.8	432	11.2	446	11	440	10.983	439.33
30%	11.2	448	11.2	448	11.1	442	11.15	446
45%	10.9	436	10.4	416	10.6	424	10.633	425.33
60%	9.65	386	9.8	390	10.1	402	9.817	392.67

Information from Table 4.8 to Table 4.11 is used to plot a graph in Figure 4.9.

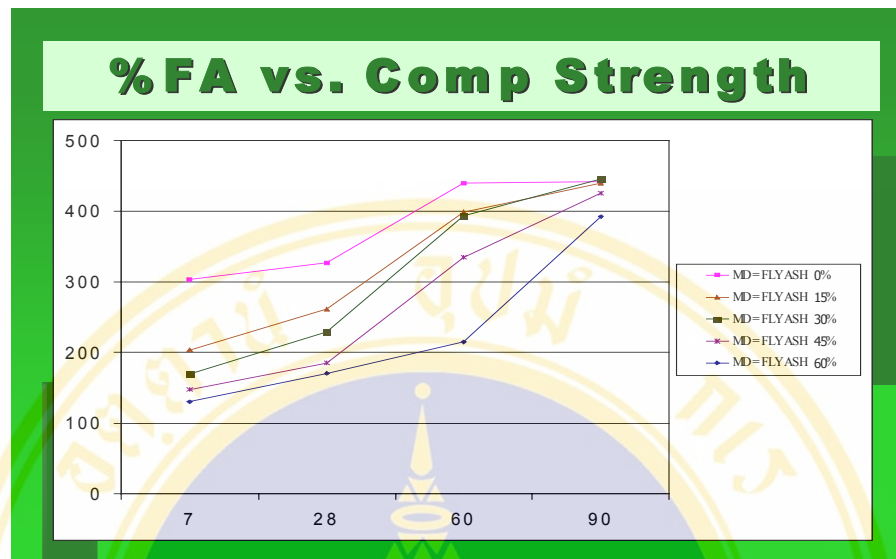


Figure 4.9: Plot of Compressive Strength and Percent Fly Ash

Relationship between concrete compressive strength and percent fly ash is shown in Figure 4.9. From the graphical illustration, it can be interpreted that the higher percentage of fly ash in concrete, the lower compressive strength, and that the long-term or ultimate strength of all percentages of fly ash would reach about the same value. In other words, concrete with higher percent fly ash would start off with lower compressive strength, but after a period of time, would gain up to about the same strength as the controlled mix with no fly ash (shown in Figure 4.9 at 90 day strength).

Information from the compressive strength test, along with other exposure and pathway-related information, will help determine types of concrete utilization, leaching concentration for exposure, and finally an estimation of human health risk.

4.3.10 Information on Transport and Utilization of ‘Sold’ Fly Ash

Each day hundreds of trucks from ready mixed concrete business come to buy fly ash from Mae Moh Plant. Usually, there are a driver and his assistant in a truck that can legally contain 30 tons (net) of fly ash. On an average, a truck will come to the plant once a week, however, some of them may come to the plant as often as 2 – 3 times a week. A truck driver has to weigh in with an empty truck, take a number, stay

in line, get loaded with fly ash at one of the silos available, weigh out, sign a paper work, and take off to his destination. The whole process takes from 1 hour to 6 hours depending on many factors. The process of loading fly ash from a silo to a truck takes 10 minutes on average, but may take up to 15 minutes (Ponlit, 2003). This is the place drivers are exposed to inhalation of fly ash containing dust, which may result in some health risks. Information on dust concentrations at silos (PM-10) was available since January 2000.

4.4 Quantification of Exposure

The basis for calculating human intake levels from exposure to total arsenic associated with the two scenarios is presented here, with each parameter described. A quantified intake represents daily dose of a chemical taken into body, averaged over some appropriate period of time, and is expressed in units of milligrams per kilogram of body weight per day (mg/kg-day). The primary source of exposure equations come from U.S. EPA's '*Risk Assessment Guideline for Superfund (RAGS)*' (U.S. EPA, 1989). The generalized equation for intake is:

$$I = C \times \frac{CR \times EFD}{BW} \times \frac{1}{AT}$$

Where:

I = intake; the amount of chemical at the exchange boundary
(mg/kg BW-day)

Chemical-related variable

C = chemical concentration; the average concentration contacted over the exposure period (e.g., mg/L water)

Variables that describe the exposed population

CR = contact rate; the amount of contaminated medium contacted per unit time or event (e.g., L/day)

EFD = exposure frequency and duration; describes how long and how often exposure occurs. Often calculated using two terms (EF and ED)

EF = exposure frequency (days/year)

ED = exposure duration (years)

BW = body weight; the average body weight over the exposure period (kg)

Assessment-determined variable

AT = averaging time; period over which exposure is averaged (days)

Exposure parameters (e.g., frequency, exposure duration) describe a receptor's exposure for a given exposure scenario. The parameters used in the Human Health Risk Assessment as input values in exposure equations are consistent with current U.S. EPA Risk Assessment Guideline and/or recent peer-reviewed literature. Where appropriate, professional judgment will be used to input exposure parameters. Both central tendency exposure (CTE) (i.e., 50th percentile value or mean) and reasonable maximum exposure (RME) (maximum concentration measured as conservative estimate) parameters are used. CTEs provide a typical or average estimate of exposure, while RMEs provide a high-end estimate of exposure. These values were never studied or recorded for this particular situation, therefore the values were based on interview information with statistical sufficiency. It is noted that RMEs occur when the body weight is reasonably minimum, according to the formula for intake.

There are 7 Possible Complete Pathways for the two scenarios.

1. Direct Ingestion (drinking water) – Residential Scenario

$$I = \frac{CW \times IR \times EF \times ED}{BW \times AT}$$

Where:

CW = Chemical Concentration in Water (mg/l)
Site-specific measured or modeled value

IR = Ingestion Rate (liters/day)
Population specific: interview/survey

EF = Exposure Frequency (days/year)
Pathway-specific value

ED = Exposure Duration (years)
70 years (lifetime; by convention) and interview/survey

BW = Body Weight (kg)
70 kg (adult, average; U.S. EPA 19891d), Age-specific value

AT = Averaging Time (period over which exposure is averaged, days)
Pathway-specific period of exposure

2. Direct Ingestion (fish) – Residential Scenario

$$I = \frac{CF \times IR \times FI \times EF \times ED}{BW \times AT}$$

Where

CF	=	Contaminant Concentration in Fish (mg/l) Measured/modeled value
IR	=	Ingestion Rate (kg/meal), interview/survey
FI	=	Fraction Ingested from Contaminated Source (unitless) Pathway-specific value (local usage pattern), assumed = 1
EF	=	Exposure Frequency (meals/year) Pathway and population-specific
ED	=	Exposure Duration (years) 70 years (lifetime; by convention)
BW	=	Body Weight (kg) 70 kg (adult, average; U.S. EPA 1989d)
AT	=	Averaging Time (period over which exposure is averaged, days) Pathway-specific

3. Dermal Contact (swimming and showering) – Residential Scenario

$$I = \frac{CW \times CR \times ET \times EF \times ED}{BW \times AT}$$

Where:

CW	=	Chemical Concentration in Water (mg/l) Site-specific measured or modeled value
CR	=	Contact Rate (liters/hour) Population specific: literature/interview/survey, 0.05 (U.S. EPA values)
ET	=	Exposure Time (hours/event): interview/survey
EF	=	Exposure Frequency (days/year) Pathway-specific value
ED	=	Exposure Duration (years) 70 years (lifetime; by convention) and interview/survey

BW = Body Weight (kg)
70 kg (adult, average; U.S. EPA 1989d), Age-specific value

AT = Averaging Time (period over which exposure is averaged, days)
Pathway-specific period of exposure

4. Dermal Contact (farming activity) – Residential Scenario

$$\text{Absorbed Dose} = \frac{\text{CW} \times \text{SA} \times \text{PC} \times \text{ET} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times \text{AT}}$$

Where:

CW = Chemical Concentration in Water (mg/l)
Site-specific measured or modeled value

SA = Skin Surface Area Available for Contact (cm²)
Population specific: literature (U.S. EPA values, age specific)

PC = Chemical-specific Dermal Permeability Constant (cm/hr): literature,
8.57 x 10⁻⁴ (U.S. EPA values)

ET = Exposure Time (hours/event): interview/survey

EF = Exposure Frequency (days/year)
Pathway-specific value

ED = Exposure Duration (years)
70 years (lifetime; by convention) and interview/survey

CF = Volumetric Conversion Factor for Water (1 liter/1000 cm³)

BW = Body Weight (kg)
70 kg (adult, average; U.S. EPA 1989d), Age-specific value

AT = Averaging Time (period over which exposure is averaged, days)
Pathway-specific period of exposure

5. Incidental Ingestion (fly ash) – Occupational Scenario

This pathway to human bodies assumes that the bodies are surrounded with solids containing element of interest, for example, at the storage site and in plant units.

$$I = \frac{\text{CS} \times \text{IR} \times \text{CF} \times \text{FI} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}}$$

Where:

CS	=	Chemical Concentration in Soil (mg/kg), site-specific measured value
IR	=	Ingestion Rate (liters/day), literature, 100 mg/day (U.S. EPA values)
CF	=	Conversion Factor (10^{-6} kg/mg)
FI	=	Fraction Ingested from Contaminated Source (unitless) Pathway-specific value (local activity pattern), assumed = 1
EF	=	Exposure Frequency (days/year) Pathway and population-specific
ED	=	Exposure Duration (years) 70 years (lifetime; by convention)
BW	=	Body Weight (kg) 70 kg (adult, average; U.S. EPA 1989d)
AT	=	Averaging Time (period over which exposure is averaged, days) Pathway-specific

6. Inhalation (particulates) – Occupational Scenario

$$I = \frac{CA \times IR \times ET \times EF \times ED}{BW \times AT}$$

Where

CA	=	Contaminant Concentration in air (mg/m^3) (measured)
IR	=	Inhalation Rate ($20 - 30 \text{ m}^3/\text{hour}$)(EPA values)
ET	=	Exposure Time (hours/day) (interview, survey)
EF	=	Exposure Frequency (days/year) Pathway and population-specific
ED	=	Exposure Duration (years) 70 years (lifetime; by convention)
BW	=	Body Weight (kg) 70 kg (adult, average; U.S. EPA 1989d)
AT	=	Averaging Time (period over which exposure is averaged, days) Pathway-specific

7. Dermal Contact (fly ash) – Occupational Scenario

$$I = \frac{CS \times CF \times SA \times AF \times ABS \times EF \times ED}{BW \times AT}$$

Where:

CS	=	Chemical Concentration in Soil (mg/kg), site-specific measured value
CF	=	Conversion Factor (10^{-6} kg/mg)
SA	=	Skin Surface Area Available for Contact (cm^2/event), literature, 500 for CTE and 1160 for RME (U.S. EPA values)
AF	=	Soil to Skin Adherence Factor (mg/cm^2), literature, 0.25 for CTE and 1.7 for RME (U.S. EPA values)
ABS	=	Absorption Factor (unitless), literature, 0.03 for CTE and RME (U.S. EPA values)
EF	=	Exposure Frequency (events/year) Pathway and population-specific, interview
ED	=	Exposure Duration (years) 70 years (lifetime; by convention)
BW	=	Body Weight (kg) 70 kg (adult, average; U.S. EPA 1989d)
AT	=	Averaging Time (period over which exposure is averaged, days) Pathway-specific

4.5 Calculation of Cancer Risks

Cancer risks are defined as ‘*incremental probability that an individual will develop cancer during his or her lifetime due to chemical exposure under the specific scenarios evaluated in human health risk assessment.*’ The ‘incremental’ implies the risk above the background cancer risk experienced by all individuals in the course of daily life. For example, if one in four Americans died of cancer, therefore, the background cancer is 0.25, or 250,000 in one million (ACS, 2000). The incremental risk is a measure of an additional estimated risk due to a specific exposure. Cancer risks are expressed as a unitless probability such as 10^{-6} , or one in a million of one

individual developing cancer over a lifetime, above background risk, as a result of exposure to arsenic in the two scenarios: residential and occupational populations.

Excess (additional) risks for exposure pathways (oral ingestion, dermal contact, and inhalation) are calculated using intake estimates (lifetime average or reasonable maximum daily doses) mentioned above. Cancer slope factors (CSFs) are described in toxicity assessment, also mentioned. Estimated intakes and CSFs are multiplied to calculate excess cancer risk according to the following equation:

$$\text{Cancer Risk} = \text{Intake (mg/kg-day)} \times \text{CSF (mg/kg-day)}^{-1}$$

For the ingestion exposure route, the estimated oral intake ('applied or administered' doses) is multiplied by CSF_{oral} , which are applicable to applied/administered doses).

In general, for dermal exposure (expressed as absorbed dose), the CSF_{oral} is adjusted to be applicable to absorbed doses (U.S. EPA, 1989; 1992a). This adjustment is made assuming that once a chemical is absorbed into the blood stream the health effects are similar regardless of whether the route of exposure was oral or dermal. However, since oral absorption for arsenic is approximately 95% in water (U.S. EPA, 1999a). and U.S. EPA recommends adjusting toxicity for dermal route only when oral absorption is less than 50% to *'obviate the need to make comparatively small adjustments in the toxicity value that would otherwise impart on the process a level of accuracy that is not supported by the scientific literature'* (U.S. EPA, 1999a), no adjustment was made to the CSF_{oral} to assess health risks from dermal exposure to both scenarios in this assessment. Therefore, to quantify risk for dermal exposure, the estimated dermal intake ('absorbed dose') is multiplied by the CSF_{oral} .

The summary of cancer risks for both scenarios are presented in Tables in Section 4.7. Since the human health risk assessment was prepared in accordance with current U.S. EPA guidelines, the estimated risks are compared to the U.S. EPA's acceptable range of 1×10^{-6} to 1×10^{-4} (U.S. EPA, 1991b), which represent 1 case in every 1,000,000 and 1 case in 10,000 population, respectively.

4.6 Modeling of Risk Contribution from Fly Ash Particulates

The modeling is aimed at determining concentrations of total arsenic in each medium that would be exposed to populations, for both scenarios-complete storage and complete sales of fly ash.

Concentrations of arsenic in solid fly ash were assumed to be consistent (averagely the same) over the modeling process. Based on existing information, the concentrations of total arsenic in air will be modeled and used for the calculations of human health risk for inhalation exposure. In addition, the total arsenic concentrations in natural water were also approximated based on dust concentration of fly ash in air. The higher the dust concentration in air, the more fly ash that has to be treated through the ash-water treatment system.

The dust concentration measurement in air done by the Electricity Authority of Thailand can be used to estimate the total amount of fly ash amount that has to be treated by the treatment system ponds. This is due to the fact that all dust, after a period of retention time in air, will settle on the floor or on parts of machines in each plant. The accumulated dust will be regularly washed and drained into the pipes leading to the ash water lake, which is the beginning of the water treatment process.

The routine measurement for dust concentrations in air is done in each plant, however the recorded data were only available since January 2000 (Appendix E). The recorded values for dust concentrations (PM10) for each silo gives a few to nine data points for modeling purposes.

For very few or no data points (units 4 – 7) and very complicated plant environmental settings, after considering the objectives of study, associated schedule, budget, and data constraints, a simple average or arithmetic means are used because it is not possible to tell the tendency or direction of the air dispersion. While, for few data points, most suitable approximation is a linear model. More complicated models require more intensive data points that are not available at this point in time.

Out of 10 units investigated, 4 units (units 4, 5, 6, 7) had very few and inadequate data points for linear modeling, therefore arithmetic means were used. After considering model selection criteria, linear relationship seemed to be the most suitable and fit well for 4 of 6 remaining units with adequate data points (units 8, 9, 11, 13). The linear correlation values were approximately between 60% and 80%.

Units 10 and 12 did not well fit linear models, therefore arithmetic means were also used. Summary of linear models are shown in the following pages.

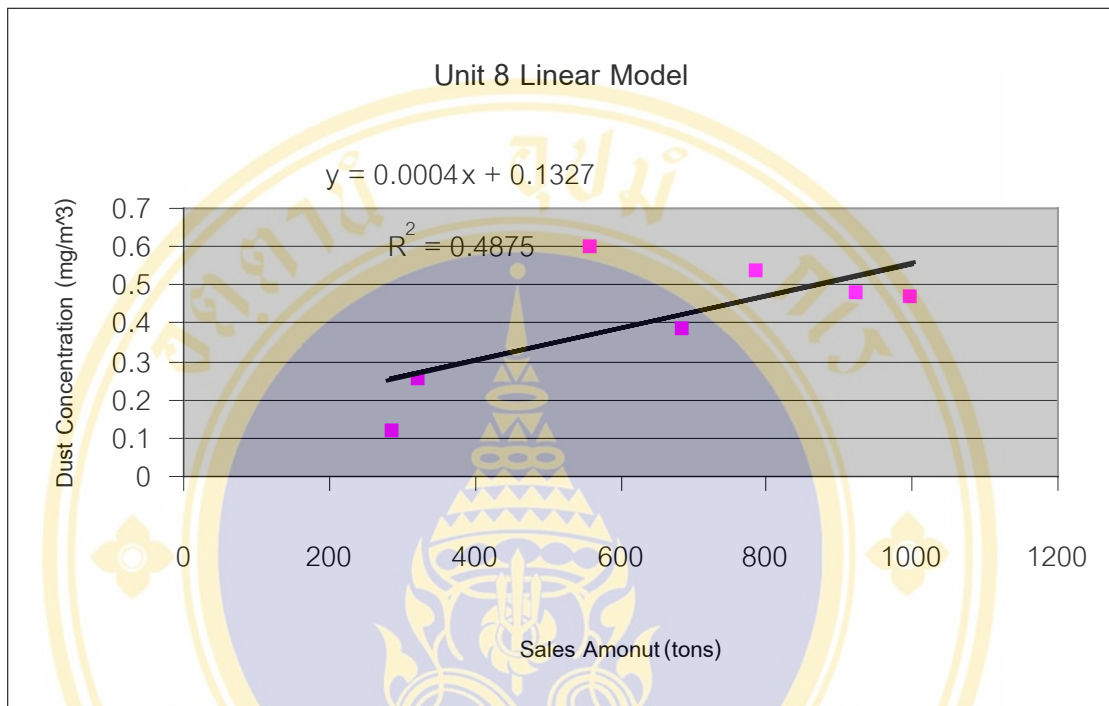


Figure 4.10: Relationship of Dust Concentration in Air and Fly Ash Sale Amount for Plant Unit 8

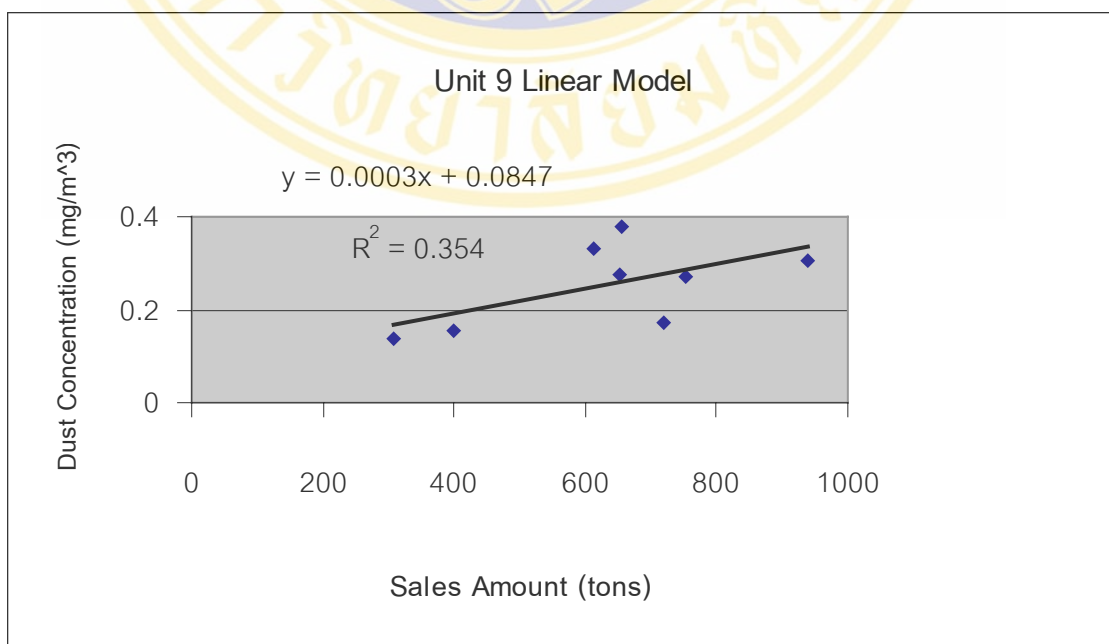


Figure 4.11: Relationship of Dust Concentration in Air and Fly Ash Sale Amount for Plant Unit 9

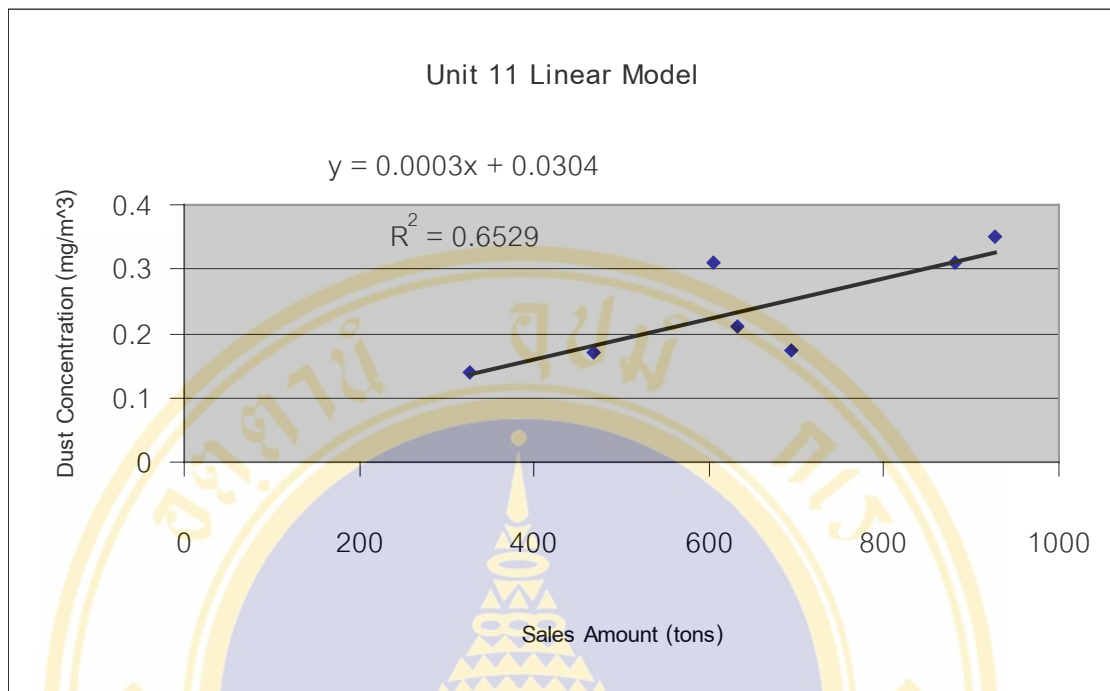


Figure 4.12: Relationship of Dust Concentration in Air and Fly Ash Sale Amount for Plant Unit 11

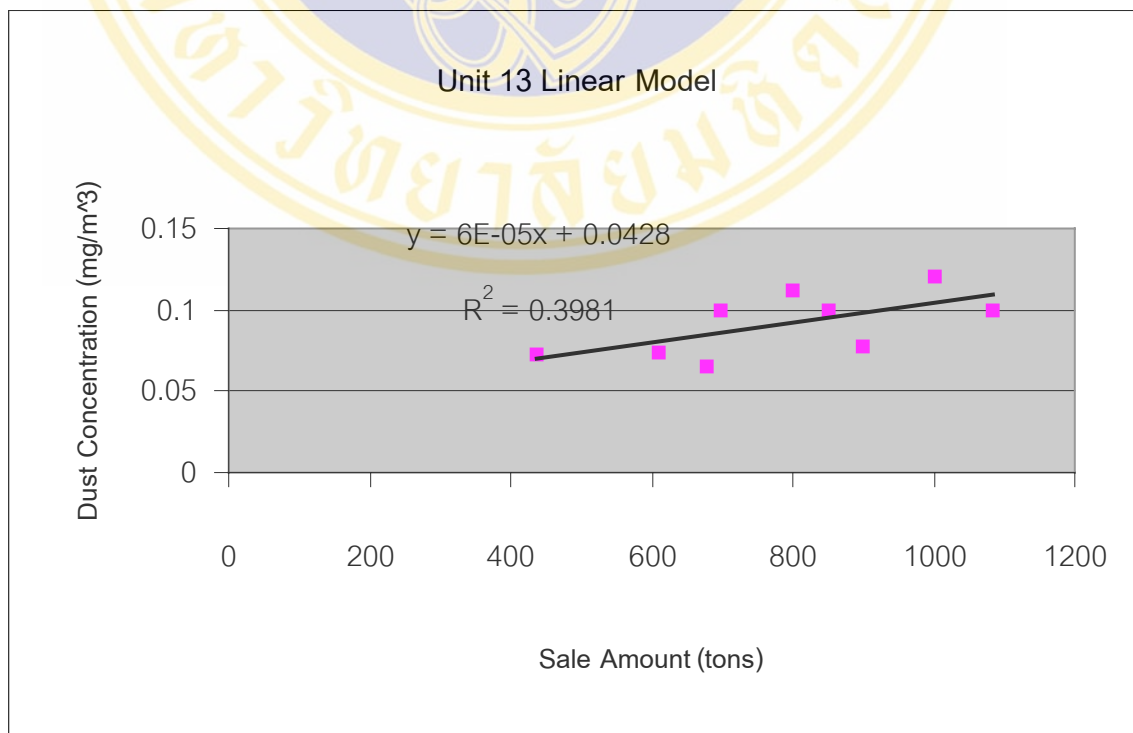


Figure 4.13: Relationship of Dust Concentration in Air and Fly Ash Sale Amount for Plant Unit 13

According to Figure 4.10, plant unit 8's linear regression line has the value of R^2 of 0.488 or the linear correlation (R) of approximately 0.70 or 70%. Figure 4.11 shows the value of R^2 of 0.354 for linear regression for plant unit 9, which means that the linear correlation is approximately 60%. While, plant unit 11 has regressed value of R^2 of 0.653 or a linear correlation of 0.81 or 81%. Lastly, plant unit 13 has the value of R^2 of 0.398 or a linear correlation of 0.63 or 63%.

Table 4.12 shows the estimation of extrapolated dust concentration in air for both scenarios: complete storage and complete sale of fly ash with detailed explanation below it.

Table 4.12: Modeling and Extrapolation of Dust Concentration in Air

Silo #	Fly Ash Produced (tons/day)	Approximate Contribution by sales amount	Average Measured Concentration	Extrapolated Concentration (100% storage)	% change (storage)	Extrapolated Concentration (100% sale)	% change (sales)
Silo 4*	600	0.0667	0.542	0.542	0	0.542	0
Silo 5*	600	0.0667	0.573	0.573	0	0.573	0
Silo 6*	600	0.0667	0.418	0.418	0	0.418	0
Silo 7*	600	0.0667	0.304	0.304	0	0.304	0
Silo 8	1100	0.122	0.408	0.1327	-67.475	0.5727	140.368
Silo 9	1100	0.122	0.253	0.0847	-66.522	0.4147	163.913
Silo 10*	1100	0.122	0.237	0.237	0	0.237	0
Silo 11	1100	0.122	0.238	0.0304	-87.227	0.3604	151.429
Silo 12*	1100	0.122	0.184	0.184	0	0.184	0
Silo 13	1100	0.122	0.0908	0.0428	-52.863	0.1088	119.824
	9,000	Avg	0.325	0.255		0.371	
		Max	0.573	0.573		0.573	
	Note:	*use average values		Total % change	-33.439	(extrapolated)	+21.415

Plants 4 – 7 are capable of producing up to 600 tons, while plants 8 – 13 can produce up to 1,100 tons of fly ash daily. Approximate contribution by sales amount is calculated according to the amount of potential production. For example, plant 5 can produce 600 tons of fly ash for possible sales, it contributes to 6.67% of total potential sales of 9,000 tons a day, while plant 13, producing up to 1,100 tons, contributes to 12.22% of total sales amount of fly ash.

The next column, average measured concentration for each plant, measured at corresponding silo, represents concentration of dust in air according to current practice (a portion of fly ash sales and a portion of storage).

When all fly ash is assumed to undergo 100% storage, extrapolation is made to find concentration with no fly ash sales. The linear model shows this concentration at the point of intersection of regression line and Y-axis. For example, for plant unit 9, the modeled concentration of dust is extrapolated to be 0.0847, the value of Y-axis where it intersects the regression line (Figure 4.11).

On the other hand, when all fly ash is assumed to undergo complete sales, extrapolation is made to find dust concentration in air according to total sales. The linear model shows this concentration at the point of intersection of regression line and potential sales amount on X-axis. For example, for plant unit 11, the modeled concentration of dust is extrapolated to be 0.3604, the value of Y-axis where the regression line intersects $X = 1,100$ tons (Figure 4.12).

For each scenario and each plant, percent change in concentration is calculated for the plants that have acceptable correlation of sales amount and dust concentration. Percent change for the rest of the plants will be zero, or no change for either scenario. The overall percent change will then be calculated by summing up multiplied percent change and the contribution. In this case, it can be interpreted that the overall dust concentration will decrease 33.44 percent if all fly ash is stored, while if all fly ash is sold, the overall dust concentration will increase by 21.42 percent. These values for extrapolated dust concentration for both scenarios will be used in the health assessment processes.

4.7 Summary of Cancer Risks

4.7.1 Measured Concentrations (Current Sales and Storage)

Summary Tables of cancer risks for current sales and storage are shown below. Occupational population and residential population are separately calculated. The total risks are the sum across all possible pathways, according to equations in sections 4.3, for each population scenario. They are then compared to acceptable values of 10^{-4} and 1.0.

4.7.1.1 Occupational Population:

**Table 4.13: Summary of Cancer for Occupational Population
(Current Sales and Storage)**

Occupational Risks	for CTE	for RME
Workers (Plants)	2.01E-06	1.01E-05
Workers (Storage Site)	1.85E-06	9.11E-06
Visitors	6.12E-08	7.06E-08

4.7.1.2 Residential Population:

Tables below illustrate summary of cancer for residential population in each village, classified by age. Risks for both central tendency exposure and reasonable maximum exposure are tabulated.

**Table 4.14: Summary of Cancer for Residential Population
of Hang Hung Village (Current Sales and Storage)**

Hang Hung	for CTE	for RME
Age	Risk	Risk
0-1	1.56E-07	6.38E-07
1- 4	1.04E-06	5.53E-06
5 -15	3.96E-07	1.91E-06
15-59	2.75E-07	1.20E-06
60 - 80	2.18E-07	9.92E-07

Table 4.15: Summary of Cancer Risks for Residential Population of Mae Moh Station (Current Sales and Storage)

Mae Moh Station	for CTE	for RME
Age	Risk	Risk
0-1	2.29E-06	1.17E-05
1- 4	4.30E-06	1.38E-05
5 -15	2.83E-06	6.88E-06
15-59	2.21E-06	4.14E-06
60 – 80	1.64E-06	3.28E-06

Table 4.16: Summary of Cancer Risks for Residential Population of Mae Lu Village (Current Sales and Storage)

Mae Lu	for CTE	for RME
Age	Risk	Risk
0-1	2.04E-06	9.35E-06
1- 4	1.32E-06	8.22E-06
5 -15	7.79E-07	3.67E-06
15-59	6.86E-07	2.75E-06
60 – 80	4.48E-07	1.97E-06

Table 4.17: Summary of Cancer Risks for Residential Population of Don Mun Village (Current Sales and Storage)

Don Mun	for CTE	for RME
Age	Risk	Risk
0-1	7.30E-08	4.43E-07
1- 4	6.34E-08	2.88E-06
5 -15	3.02E-08	1.01E-06
15-59	2.51E-08	6.09E-07
60 – 80	1.02E-08	5.16E-07

Table 4.18: Summary of Cancer Risks for Residential Population of Hua Sua Village (Current Sales and Storage)

Hua Sua	for CTE	for RME
Age	Risk	Risk
0-1	1.89E-06	1.19E-05
1- 4	2.45E-06	9.89E-06
5 -15	1.05E-06	4.09E-06
15-59	8.42E-07	2.47E-06
60 – 80	6.03E-07	1.98E-06

Table 4.19: Summary of Cancer Risks for Residential Population of Sop Rai Village (Current Sales and Storage)

Sop Rai	for CTE	for RME
Age	Risk	Risk
0-1	6.20E-08	3.90E-07
1- 4	4.73E-07	2.48E-06
5 -15	1.77E-07	8.79E-07
15-59	1.23E-07	5.37E-07
60 – 80	9.95E-08	4.55E-07

Table 4.20: Summary of Cancer Risks for Residential Population of Ban Kom Village (Current Sales and Storage)

Ban Kom	for CTE	for RME
Age	Risk	Risk
0-1	1.57E-06	9.61E-06
1- 4	1.74E-06	5.74E-06
5 -15	6.50E-07	2.55E-06
15-59	5.56E-07	1.36E-06
60 – 80	5.04E-07	1.20E-06

Table 4.21: Summary of Cancer Risks for Residential Population of Ban Mai (Mu 1) Village (Current Sales and Storage)

Ban Mai (Mu 1)	for CTE	for RME
Age	Risk	Risk
0-1	5.75E-08	2.76E-07
1- 4	4.46E-07	1.85E-06
5 -15	1.69E-07	6.56E-07
15-59	1.15E-07	4.03E-07
60 – 80	9.38E-08	3.19E-07

Table 4.22: Summary of Cancer Risks for Residential Population of Ban Mai (Mu 8) Village (Current Sales and Storage)

Ban Mai (Mu 8)	for CTE	for RME
Age	Risk	Risk
0-1	2.88E-08	3.68E-07
1- 4	6.57E-07	5.96E-06
5 -15	2.45E-07	2.03E-06
15-59	1.65E-07	1.23E-06
60 – 80	1.39E-07	1.07E-06

Table 4.23: Summary of Cancer Risks for Residential Population of Pong Pa Pao Village (Current Sales and Storage)

Pong Pa Pao	for CTE	for RME
Age	Risk	Risk
0-1	2.25E-08	3.13E-07
1- 4	3.77E-07	2.22E-06
5 -15	1.43E-07	7.73E-07
15-59	9.75E-08	4.77E-07
60 - 80	7.96E-08	3.98E-07

Table 4.24: Summary of Cancer Risks for Residential Population of Sop Po Village (Current Sales and Storage)

Sop Po	for CTE	for RME
Age	Risk	Risk
0-1	6.38E-08	4.91E-07
1- 4	5.81E-07	2.62E-06
5 -15	2.17E-07	8.94E-07
15-59	1.45E-07	5.54E-07
60 – 80	1.24E-07	4.62E-07

Table 4.25: Summary of Cancer Risks for Residential Population of Ban Luk Village (Current Sales and Storage)

Ban Luk	for CTE	for RME
Age	Risk	Risk
0-1	3.79E-08	3.63E-07
1- 4	1.27E-06	3.38E-06
5 -15	4.74E-07	1.19E-06
15-59	3.07E-07	7.09E-07
60 – 80	2.72E-07	6.10E-07

Table 4.26: Summary of Cancer Risks for Residential Population of Ban Luk Tai Village (Current Sales and Storage)

Ban Luk Tai	for CTE	for RME
Age	Risk	Risk
0-1	2.53E-08	3.63E-07
1- 4	1.28E-06	5.87E-06
5 -15	4.71E-07	2.00E-06
15-59	3.08E-07	1.21E-06
60 – 80	2.72E-07	1.05E-06

Table 4.27: Summary of Cancer Risks for Residential Population of Nam Thong Village (Current Sales and Storage)

Nam Thong	for CTE	for RME
Age	Risk	Risk
0-1	6.68E-08	4.20E-07
1- 4	9.82E-07	3.45E-06
5 -15	3.66E-07	1.19E-06
15-59	2.39E-07	7.17E-07
60 – 80	2.11E-07	6.23E-07

Table 4.28: Summary of Cancer Risks for Residential Population of Nong Thoi Village (Current Sales and Storage)

Nong Thoi	for CTE	for RME
Age	Risk	Risk
0-1	3.90E-08	2.48E-07
1- 4	3.00E-07	1.94E-06
5 -15	1.11E-07	6.68E-07
15-59	7.74E-08	4.13E-07
60 – 80	6.48E-08	3.56E-07

Table 4.29: Summary of Cancer Risks for Residential Population of Ban Hom Village (Current Sales and Storage)

Ban Hom	for CTE	for RME
Age	Risk	Risk
0-1	1.95E-08	2.48E-07
1- 4	3.00E-07	1.98E-06
5 -15	1.11E-07	6.81E-07
15-59	7.74E-08	4.13E-07
60 – 80	6.32E-08	3.49E-07

Table 4.30: Summary of Cancer Risks for Residential Population of Na Kwao Village (Current Sales and Storage)

Na Kwao	for CTE	for RME
Age	Risk	Risk
0-1	1.35E-08	8.88E-08
1- 4	2.15E-07	2.08E-06
5 -15	7.95E-08	6.95E-07
15-59	5.40E-08	4.33E-07
60 – 80	4.53E-08	3.76E-07

Table 4.31: Summary of Cancer Risks for Residential Population of Na Khot Village (Current Sales and Storage)

Na Khot	for CTE	for RME
Age	Risk	Risk
0-1	3.10E-08	1.58E-07
1- 4	1.39E-07	1.99E-06
5 -15	4.92E-08	6.65E-07
15-59	3.46E-08	4.14E-07
60 – 80	2.74E-08	3.53E-07

Table 4.32: Summary of Cancer Risks for Residential Population of Pa Tan Nua Village (Current Sales and Storage)

Pa Tan Nua	for CTE	for RME
Age	Risk	Risk
0-1	3.20E-08	1.88E-07
1- 4	2.35E-07	4.05E-06
5 -15	8.45E-08	1.35E-06
15-59	5.93E-08	8.28E-07
60 – 80	4.79E-08	7.22E-07

Table 4.33: Summary of Cancer Risks for Residential Population of Pa Tan Tai Village (Current Sales and Storage)

Pa Tan Tai	for CTE	for RME
Age	Risk	Risk
0-1	3.20E-08	1.41E-07
1- 4	4.50E-07	3.49E-06
5 -15	1.68E-07	1.17E-06
15-59	1.11E-07	7.09E-07
60 – 80	9.46E-08	6.20E-07

Table 4.34: Summary of Cancer Risks for Residential Population of Sop Tha Village (Current Sales and Storage)

Sop Tha	for CTE	for RME
Age	Risk	Risk
0-1	2.55E-08	2.66E-07
1- 4	3.21E-07	1.18E-06
5 -15	1.17E-07	4.05E-07
15-59	7.78E-08	2.46E-07
60 – 80	6.73E-08	2.02E-07

Table 4.35: Summary of Cancer Risks for Residential Population of Ban Nong (Mu 4 and Mu 9) Villages (Current Sales and Storage)

Ban Nong (Mu 4 and 9)	for CTE	for RME
Age	Risk	Risk
0-1	2.18E-08	1.20E-07
1- 4	1.47E-07	9.61E-07
5 -15	5.43E-08	3.27E-07
15-59	3.64E-08	2.08E-07
60 - 80	3.04E-08	1.73E-07

Table 4.36: Summary of Cancer Risks for Residential Population of Ban To Village (Current Sales and Storage)

Ban To	for CTE	for RME
Age	Risk	Risk
0-1	7.75E-09	1.69E-07
1- 4	1.39E-07	1.07E-06
5 -15	5.02E-08	3.62E-07
15-59	3.39E-08	2.22E-07
60 – 80	2.86E-08	1.89E-07

Table 4.37: Summary of Cancer Risks for Residential Population of Ban Pao Village (Current Sales and Storage)

Ban Pao	for CTE	for RME
Age	Risk	Risk
0-1	1.30E-08	1.31E-07
1- 4	1.08E-07	1.37E-06
5 -15	3.92E-08	4.51E-07
15-59	2.71E-08	2.78E-07
60 – 80	2.23E-08	2.42E-07

Table 4.38: Summary of Cancer Risks for Residential Population of Wang Phrao Village (Current Sales and Storage)

Wang Phrao	for CTE	for RME
Age	Risk	Risk
0-1	4.00E-09	3.50E-08
1- 4	9.52E-08	6.63E-07
5 -15	3.53E-08	2.21E-07
15-59	2.35E-08	1.35E-07
60 – 80	1.99E-08	1.18E-07

Table 4.39: Summary of Cancer Risks for Residential Population of Sop Chang Village (Current Sales and Storage)

Sop Chang	for CTE	for RME
Age	Risk	Risk
0-1	3.00E-09	2.00E-08
1- 4	3.69E-08	1.95E-07
5 -15	1.41E-08	6.67E-08
15-59	9.71E-09	4.11E-08
60 – 80	7.71E-09	3.50E-08

4.7.1.3 Utilization Population

There are three groups of exposed populations in this scenario, namely, the truck drivers, the workers at ready-mix concrete plants, and concrete products end users. Exposure will be estimated based on interview information for each group of population. The possible routes of exposure are listed below:

Truck Drivers:	Dermal Contact and Inhalation
Workers at Ready-mix Concrete Plants:	Dermal Contact and Inhalation
Concrete Products Users:	Dermal Contact

Incidental Ingestion pathway is not assessed for the utilization population because the risk due to this pathway is negligible compared to the pathways stated above. Truck drivers, workers at ready mixed concrete plants, and concrete product users do not work in area surrounded by solids of fly ash particles. Dermal Contact and Inhalation are the two major pathways that contribute to overall risks in this group of population.

The summary of cancer risks for current sales and storage, is shown below:

Table 4.40: Summary of Risks for Utilization Population (Current Storage and Sale)

Utilization Scenario	(Current Storage and Sale)	Utilization Scenario	(Current Storage and Sale)
Total Risk for CTE	Risk	Total Risk for RME	Risk
	-		-
Truck Drivers	4.0093E-07	Truck Drivers	5.87E-06
Workers (Ready Mixed Concrete Plants)	4.5934E-08	Workers (Ready Mixed Concrete Plants)	1.03E-06
End Users:		End Users:	
- General Structure	1.75E-10	- General Structure	6.91E-09
- Road Surface	1.33E-10	- Road Surface	5.26E-09
- Special Structure	3.17E-10	- Special Structure	1.25E-08

Truck drivers are assessed to have highest cancer risks of the utilization population as shown in Table 4.40 above. Inhalation of particulate fly ash contributed the most to overall cancer risks. Nevertheless, such risks are well within an acceptable limit suggested by the U.S. EPA.

4.7.2 Modeled Concentrations -- Complete Storage

This case assumes that all fly ash produced is transported to the storage site with no fly ash sold to customers for construction purposes. Modeled concentrations of dust concentration in air, and thus total arsenic concentration will be input in risk quantification processes. Concentrations of arsenic in river water will also be estimated, assuming that the efficiency of treatment system stays the same, and that the arsenic dispersion along the river is constant.

Summary Tables of cancer risks for extrapolated complete storage are shown below. Occupational population and residential population are separately calculated. The total risks are the sum across all possible pathways, according to equations in sections 4.3, for each population scenario. They are then compared to acceptable values of 10^{-4} and 1.0.

4.7.2.1 Occupational Population

Table 4.41: Summary of Cancer Risks for Occupational Population (Complete Storage)

Occupational	for CTE	for RME
Total	Risk	Risk
Workers (plants)	1.6222E-06	1.01E-05
Workers (storage)	1.4913E-06	9.11E-06
Visitors	5.017E-08	7.06E-08

4.7.2.2 Residential Population

In this scenario, an adjusting factor of 0.6656 from Section 4.7 is applied to the calculation of cancer risks. The results of summary risks are shown in Tables 4.42 to Table 4.67 below.

Table 4.42: Summary of Cancer Risks for Residential Population of Hang Hung (Complete Storage)

Hang Hung	for CTE	for RME
Age	Risk	Risk
0-1	1.038E-07	4.24E-07
1- 4	6.925E-07	3.68E-06
5 -15	2.635E-07	1.27E-06
15-59	1.828E-07	8.01E-07
60 – 80	1.45E-07	6.6E-07

Table 4.43: Summary of Cancer Risks for Residential Population of Mae Moh Station Village (Complete Storage)

Mae Moh Station	for CTE	for RME
Age	Risk	Risk
0-1	1.523E-06	7.81E-06
1- 4	2.864E-06	9.16E-06
5 -15	1.881E-06	4.58E-06
15-59	1.468E-06	2.76E-06
60 – 80	1.09E-06	2.18E-06

Table 4.44: Summary of Cancer Risks for Residential Population of Mae Lu Village (Complete Storage)

Mae Lu	for CTE	for RME
Age	Risk	Risk
0-1	1.36E-06	6.22E-06
1- 4	8.816E-07	2.16E-06
5 -15	5.183E-07	1.34E-06
15-59	4.567E-07	1.17E-06
60 – 80	2.985E-07	7.12E-07

Table 4.45: Summary of Cancer Risks for Residential Population of Don Mun Village (Complete Storage)

Don Mun	for CTE	for RME
Age	Risk	Risk
0-1	4.859E-08	2.95E-07
1- 4	4.218E-08	2.72E-07
5 -15	2.007E-08	1.24E-07
15-59	1.668E-08	7.69E-08
60 – 80	6.766E-09	4.48E-08

Table 4.46: Summary of Cancer Risks for Residential Population of Hua Sua Village (Complete Storage)

Hua Sua	for CTE	for RME
Age	Risk	Risk
0-1	1.259E-06	7.92E-06
1- 4	1.633E-06	2.81E-06
5 -15	6.957E-07	1.47E-06
15-59	5.605E-07	8.88E-07
60 – 80	4.017E-07	6.35E-07

Table 4.47: Summary of Cancer Risks for Residential Population of Sop Rai Village (Complete Storage)

Sop Rai	for CTE	for RME
Age	Risk	Risk
0-1	4.127E-08	2.6E-07
1- 4	3.151E-07	2.18E-07
5 -15	1.178E-07	1.06E-07
15-59	8.205E-08	7.04E-08
60 – 80	6.625E-08	4.19E-08

Table 4.48: Summary of Cancer Risks for Residential Population of Ban Kom Village (Complete Storage)

Ban Kom	for CTE	for RME
Age	Risk	Risk
0-1	1.045E-06	6.4E-06
1- 4	1.157E-06	2.14E-06
5 -15	4.327E-07	1.14E-06
15-59	3.701E-07	5.69E-07
60 – 80	3.355E-07	4.92E-07

Table 4.49: Summary of Cancer Risks for Residential Population of Ban Mai (Mu 1) Village (Complete Storage)

Ban Mai (Mu 1)	for CTE	for RME
Age	Risk	Risk
0-1	3.827E-08	1.83E-07
1- 4	2.966E-07	2.21E-07
5 -15	1.125E-07	9.99E-08
15-59	7.64E-08	6.62E-08
60 – 80	6.24E-08	2.89E-08

Table 4.50: Summary of Cancer Risks for Residential Population of Ban Mai (Mu 8) Village (Complete Storage)

Ban Mai (Mu 8)	for CTE	for RME
Age	Risk	Risk
0-1	1.914E-08	2.45E-07
1- 4	4.37E-07	4.34E-07
5 -15	1.63E-07	1.71E-07
15-59	1.096E-07	1.12E-07
60 – 80	9.281E-08	6.77E-08

Table 4.51: Summary of Cancer Risks for Residential Population of Pong Pa Pao Village (Complete Storage)

Pong Pa Pao	for CTE	for RME
Age	Risk	Risk
0-1	1.498E-08	2.08E-07
1- 4	2.512E-07	2.09E-07
5 -15	9.509E-08	9.16E-08
15-59	6.487E-08	6.38E-08
60 – 80	5.296E-08	3.46E-08

Table 4.52: Summary of Cancer Risks for Residential Population of Sop Po Village (Complete Storage)

Sop Po	for CTE	for RME
Age	Risk	Risk
0-1	4.243E-08	3.27E-07
1- 4	3.87E-07	2.63E-07
5 -15	1.443E-07	1E-07
15-59	9.648E-08	7.22E-08
60 – 80	8.246E-08	3.78E-08

Table 4.53: Summary of Cancer Risks for Residential Population of Ban Luk Village (Complete Storage)

Ban Luk	for CTE	for RME
Age	Risk	Risk
0-1	2.521E-08	2.41E-07
1- 4	8.43E-07	2.64E-07
5 -15	3.157E-07	1.27E-07
15-59	2.042E-07	7.43E-08
60 – 80	1.813E-07	4.42E-08

Table 4.54: Summary of Cancer Risks for Residential Population of Ban Luk Tai Village (Complete Storage)

Ban Luk Tai	for CTE	for RME
Age	Risk	Risk
0-1	1.681E-08	2.41E-07
1- 4	8.51E-07	4.28E-07
5 -15	3.133E-07	1.7E-07
15-59	2.051E-07	1.06E-07
60 – 80	1.813E-07	6.75E-08

Table 4.55: Summary of Cancer Risks for Residential Population of Nam Thong Village (Complete Storage)

Nam Thong	for CTE	for RME
Age	Risk	Risk
0-1	4.443E-08	2.8E-07
1- 4	6.539E-07	3E-07
5 -15	2.434E-07	1.25E-07
15-59	1.588E-07	7.82E-08
60 – 80	1.402E-07	5.15E-08

Table 4.56: Summary of Cancer Risks for Residential Population of Nong Thoi Village (Complete Storage)

Nong Thoi	for CTE	for RME
Age	Risk	Risk
0-1	2.596E-08	1.65E-07
1- 4	1.999E-07	2.06E-07
5 -15	7.394E-08	8.26E-08
15-59	5.15E-08	5.73E-08
60 – 80	4.312E-08	3.93E-08

Table 4.57: Summary of Cancer Risks for Residential Population of Ban Hom Village (Complete Storage)

Ban Hom	for CTE	for RME
Age	Risk	Risk
0-1	1.298E-08	1.65E-07
1- 4	1.999E-07	2.31E-07
5 -15	7.394E-08	9.09E-08
15-59	5.15E-08	5.73E-08
60 – 80	4.203E-08	3.48E-08

Table 4.58: Summary of Cancer Risks for Residential Population of Na Kwao Village (Complete Storage)

Na Kwao	for CTE	for RME
Age	Risk	Risk
0-1	8.986E-09	5.91E-08
1- 4	1.431E-07	2.79E-07
5 -15	5.293E-08	9.3E-08
15-59	3.595E-08	6.64E-08
60 – 80	3.012E-08	4.85E-08

Table 4.59: Summary of Cancer Risks for Residential Population of Na Khot Village (Complete Storage)

Na Khot	for CTE	for RME
Age	Risk	Risk
0-1	2.063E-08	1.05E-07
1- 4	9.277E-08	2.46E-07
5 -15	3.275E-08	8.28E-08
15-59	2.304E-08	5.98E-08
60 – 80	1.823E-08	3.87E-08

Table 4.60: Summary of Cancer Risks for Residential Population of Pa Tan Nua Village (Complete Storage)

Pa Tan Nua	for CTE	for RME
Age	Risk	Risk
0-1	2.13E-08	1.25E-07
1- 4	1.562E-07	4.86E-07
5 -15	5.625E-08	1.59E-07
15-59	3.945E-08	1.1E-07
60 – 80	3.191E-08	7.92E-08

Table 4.61: Summary of Cancer Risks for Residential Population of Pa Tan Tai Village (Complete Storage)

Pa Tan Tai	for CTE	for RME
Age	Risk	Risk
0-1	2.13E-08	9.36E-08
1- 4	2.994E-07	4.29E-07
5 -15	1.116E-07	1.5E-07
15-59	7.371E-08	9.33E-08
60 – 80	6.294E-08	6.89E-08

Table 4.62: Summary of Cancer Risks for Residential Population of Sop Tha Village (Complete Storage)

Sop Tha	for CTE	for RME
Age	Risk	Risk
0-1	1.697E-08	1.77E-07
1- 4	2.137E-07	1.95E-07
5 -15	7.796E-08	7.25E-08
15-59	5.175E-08	4.55E-08
60 – 80	4.476E-08	2.71E-08

Table 4.63: Summary of Cancer Risks for Residential Population of Ban Nong (Mu 4 and Mu 9) Village (Complete Storage)

Ban Nong (Mu 4 and 9)	for CTE	for RME
Age	Risk	Risk
0-1	1.448E-08	7.99E-08
1- 4	9.753E-08	1.86E-07
5 -15	3.612E-08	6.62E-08
15-59	2.42E-08	4.76E-08
60 – 80	2.026E-08	3.24E-08

Table 4.64: Summary of Cancer Risks for Residential Population of Ban To Village (Complete Storage)

Ban To	for CTE	for RME
Age	Risk	Risk
0-1	5.158E-09	1.12E-07
1- 4	9.221E-08	2.11E-07
5 -15	3.34E-08	7.45E-08
15-59	2.255E-08	4.79E-08
60 – 80	1.904E-08	3.51E-08

Table 4.65: Summary of Cancer Risks for Residential Population of Ban Pao Village (Complete Storage)

Ban Pao	for CTE	for RME
Age	Risk	Risk
0-1	8.653E-09	8.74E-08
1- 4	7.21E-08	3.25E-07
5 -15	2.606E-08	1.06E-07
15-59	1.807E-08	6.81E-08
60 – 80	1.484E-08	5.49E-08

Table 4.66: Summary of Cancer Risks for Residential Population of Wang Phrao Village (Complete Storage)

Wang Phrao	for CTE	for RME
Age	Risk	Risk
0-1	2.662E-09	2.33E-08
1- 4	6.339E-08	2.52E-07
5 -15	2.348E-08	8.41E-08
15-59	1.562E-08	5.19E-08
60 – 80	1.325E-08	4.42E-08

Table 4.67: Summary of Cancer Risks for Residential Population of Sop Chang Village (Complete Storage)

Sop Chang	for CTE	for RME
Age	Risk	Risk
0-1	1.997E-09	1.33E-08
1- 4	2.458E-08	1.25E-07
5 -15	9.369E-09	4.26E-08
15-59	6.465E-09	2.63E-08
60 – 80	5.13E-09	2.23E-08

4.7.2.3 Utilization Population

There will be no additional risks due to arsenic in this case because all fly ash is assumed to be completely stored and no fly ash is sold for any types of utilization.

4.7.3 Modeled Complete Sales

This case assumes complete sales of fly ash to customers for construction materials purposes. Similarly, modeled values for arsenic particulate concentrations in air and total arsenic concentration in river water will be input in the risk quantification processes.

Summary Tables of cancer risks for extrapolated complete sales are shown below. Occupational population and residential population are separately calculated. The total risks are the sum of all risks across all possible pathways, according to equations in sections 4.3, for each population scenario. They are then compared to acceptable values of 10^{-4} and 1.0.

4.7.3.1 Occupational Population

Risks associated with occupational population for complete sale of fly ash for workers at storage site are assessed to be zero. There will be no workers at storage site in this particular setting.

Table 4.68: Summary of Cancer Risks for Occupational Population (Complete Sales)

Occupational	for CTE	for RME
	Risk	Risk
Total		
Workers	2.3E-06	1.01E-05
(plants)		
Workers	0	0
(storage)		
Visitors	6.9E-08	7.06E-08

4.7.3.2 Residential Population

According to the linear model, adjusting factors of 0.6656 for complete fly ash storage scenario and 1.2142 for complete fly ash sale scenario are applied to final risks in Tables on the next pages.

Table 4.69: Summary of Cancer Risks for Residential Population of Hang Hung Village (Complete Sales)

Hang Hung	for CTE	for RME
Age	Risk	Risk
0-1	1.9E-07	7.7E-07
1- 4	1.3E-06	6.7E-06
5 -15	4.8E-07	2.3E-06
15-59	3.3E-07	1.5E-06
60 – 80	2.6E-07	1.2E-06

Table 4.70: Summary of Cancer Risks for Residential Population of Mae Moh Station Village (Complete Sales)

Mae Moh Station	for CTE	for RME
Age	Risk	Risk
0-1	2.8E-06	1.4E-05
1- 4	5.2E-06	1.7E-05
5 -15	3.4E-06	8.4E-06
15-59	2.7E-06	5E-06
60 – 80	2E-06	4E-06

Table 4.71: Summary of Cancer Risks for Residential Population of Mae Lu Village (Complete Sales)

Mae Lu	for CTE	for RME
Age	Risk	Risk
0-1	2.5E-06	1.1E-05
1- 4	1.6E-06	3.9E-06
5 -15	9.5E-07	2.4E-06
15-59	8.3E-07	2.1E-06
60 – 80	5.4E-07	1.3E-06

Table 4.72: Summary of Cancer Risks for Residential Population of Don Mun Village (Complete Sales)

Don Mun	for CTE	for RME
Age	Risk	Risk
0-1	8.9E-08	5.4E-07
1- 4	7.7E-08	5E-07
5 -15	3.7E-08	2.3E-07
15-59	3E-08	1.4E-07
60 – 80	1.2E-08	8.2E-08

Table 4.73: Summary of Cancer Risks for Residential Population of Hua Sua Village (Complete Sales)

Hua Sua	for CTE	for RME
Age	Risk	Risk
0-1	2.3E-06	1.4E-05
1- 4	3E-06	5.1E-06
5 -15	1.3E-06	2.7E-06
15-59	1E-06	1.6E-06
60 – 80	7.3E-07	1.2E-06

Table 4.74: Summary of Cancer Risks for Residential Population of Sop Rai Village (Complete Sales)

Sop Rai	for CTE	for RME
Age	Risk	Risk
0-1	7.5E-08	4.7E-07
1- 4	5.7E-07	4E-07
5 -15	2.1E-07	1.9E-07
15-59	1.5E-07	1.3E-07
60 – 80	1.2E-07	7.6E-08

Table 4.75: Summary of Cancer Risks for Residential Population of Ban Kom Village (Complete Sales)

Ban Kom	for CTE	for RME
Age	Risk	Risk
0-1	1.9E-06	1.2E-05
1- 4	2.1E-06	3.9E-06
5 -15	7.9E-07	2.1E-06
15-59	6.8E-07	1E-06
60 – 80	6.1E-07	9E-07

Table 4.76: Summary of Cancer Risks for Residential Population of Ban Mai (Mu 1) Village (Complete Sales)

Ban Mai (Mu 1)	for CTE	for RME
Age	Risk	Risk
0-1	7E-08	3.3E-07
1- 4	5.4E-07	4E-07
5 -15	2.1E-07	1.8E-07
15-59	1.4E-07	1.2E-07
60 – 80	1.1E-07	5.3E-08

Table 4.77: Summary of Cancer Risks for Residential Population of Ban Mai (Mu 8) Village (Complete Sales)

Ban Mai (Mu 8)	for CTE	for RME
Age	Risk	Risk
0-1	3.5E-08	4.5E-07
1- 4	8E-07	7.9E-07
5 -15	3E-07	3.1E-07
15-59	2E-07	2E-07
60 – 80	1.7E-07	1.2E-07

Table 4.78: Summary of Cancer Risks for Residential Population of Pong Pa Pao Village (Complete Sales)

Pong Pa Pao	for CTE	for RME
Age	Risk	Risk
0-1	2.7E-08	3.8E-07
1- 4	4.6E-07	3.8E-07
5 -15	1.7E-07	1.7E-07
15-59	1.2E-07	1.2E-07
60 – 80	9.7E-08	6.3E-08

Table 4.79: Summary of Cancer Risks for Residential Population of Sop Po Village (Complete Sales)

Sop Po	for CTE	for RME
Age	Risk	Risk
0-1	7.7E-08	6E-07
1- 4	7.1E-07	4.8E-07
5 -15	2.6E-07	1.8E-07
15-59	1.8E-07	1.3E-07
60 – 80	1.5E-07	6.9E-08

Table 4.80: Summary of Cancer Risks for Residential Population of Ban Luk Village (Complete Sales)

Ban Luk	for CTE	for RME
Age	Risk	Risk
0-1	4.6E-08	4.4E-07
1- 4	1.5E-06	4.8E-07
5 -15	5.8E-07	2.3E-07
15-59	3.7E-07	1.4E-07
60 – 80	3.3E-07	8.1E-08

Table 4.81: Summary of Cancer Risks for Residential Population of Ban Luk Tai Village (Complete Sales)

Ban Luk Tai	for CTE	for RME
Age	Risk	Risk
0-1	3.1E-08	4.4E-07
1- 4	1.6E-06	7.8E-07
5 -15	5.7E-07	3.1E-07
15-59	3.7E-07	1.9E-07
60 – 80	3.3E-07	1.2E-07

Table 4.82: Summary of Cancer Risks for Residential Population of Nam Thong Village (Complete Sales)

Nam Thong	for CTE	for RME
Age	Risk	Risk
0-1	8.1E-08	5.1E-07
1- 4	1.2E-06	5.5E-07
5 -15	4.4E-07	2.3E-07
15-59	2.9E-07	1.4E-07
60 – 80	2.6E-07	9.4E-08

Table 4.83: Summary of Cancer Risks for Residential Population of Nong Thoi Village (Complete Sales)

Nong Thoi	for CTE	for RME
Age	Risk	Risk
0-1	4.7E-08	3E-07
1- 4	3.6E-07	3.8E-07
5 -15	1.3E-07	1.5E-07
15-59	9.4E-08	1E-07
60 – 80	7.9E-08	7.2E-08

Table 4.84: Summary of Cancer Risks for Residential Population of Ban Hom Village (Complete Sales)

Ban Hom	for CTE	for RME
Age	Risk	Risk
0-1	2.4E-08	2.4E-08
1- 4	3.6E-07	3.6E-07
5 -15	1.3E-07	1.3E-07
15-59	9.4E-08	9.4E-08
60 – 80	7.7E-08	7.7E-08

Table 4.85: Summary of Cancer Risks for Residential Population of Na Kwao Village (Complete Sales)

Na Kwao	for CTE	for RME
Age	Risk	Risk
0-1	1.6E-08	1.1E-07
1- 4	2.6E-07	5.1E-07
5 -15	9.7E-08	1.7E-07
15-59	6.6E-08	1.2E-07
60 – 80	5.5E-08	8.8E-08

Table 4.86: Summary of Cancer Risks for Residential Population of Na Khot Village (Complete Sales)

Na Khot	for CTE	for RME
Age	Risk	Risk
0-1	3.8E-08	1.9E-07
1- 4	1.7E-07	4.5E-07
5 -15	6E-08	1.5E-07
15-59	4.2E-08	1.1E-07
60 – 80	3.3E-08	7.1E-08

Table 4.87: Summary of Cancer Risks for Residential Population of Pa Tan Nua Village (Complete Sales)

Pa Tan Nua	for CTE	for RME
Age	Risk	Risk
0-1	3.9E-08	2.3E-07
1- 4	2.8E-07	8.9E-07
5 -15	1E-07	2.9E-07
15-59	7.2E-08	2E-07
60 – 80	5.8E-08	1.4E-07

Table 4.88: Summary of Cancer Risks for Residential Population of Pa Tan Tai Village (Complete Sales)

Pa Tan Tai	for CTE	for RME
Age	Risk	Risk
0-1	3.9E-08	1.7E-07
1- 4	5.5E-07	7.8E-07
5 -15	2E-07	2.7E-07
15-59	1.3E-07	1.7E-07
60 – 80	1.1E-07	1.3E-07

Table 4.89: Summary of Cancer Risks for Residential Population of Sop Tha Village (Complete Sales)

Sop Tha	for CTE	for RME
Age	Risk	Risk
0-1	3.1E-08	3.2E-07
1- 4	3.9E-07	3.6E-07
5 -15	1.4E-07	1.3E-07
15-59	9.4E-08	8.3E-08
60 – 80	8.2E-08	4.9E-08

Table 4.90: Summary of Cancer Risks for Residential Population of Ban Nong (Mu 4 and Mu 9) Village (Complete Sales)

Ban Nong (Mu 4 and 9)	for CTE	for RME
Age	Risk	Risk
0-1	2.6E-08	1.5E-07
1- 4	1.8E-07	3.4E-07
5 -15	6.6E-08	1.2E-07
15-59	4.4E-08	8.7E-08
60 – 80	3.7E-08	5.9E-08

Table 4.91: Summary of Cancer Risks for Residential Population of Ban To Village (Complete Sales)

Ban To	for CTE	for RME
Age	Risk	Risk
0-1	9.4E-09	2E-07
1- 4	1.7E-07	3.8E-07
5 -15	6.1E-08	1.4E-07
15-59	4.1E-08	8.7E-08
60 – 80	3.5E-08	6.4E-08

Table 4.92: Summary of Cancer Risks for Residential Population of Ban Pao Village (Complete Sales)

Ban Pao	for CTE	for RME
Age	Risk	Risk
0-1	1.6E-08	1.6E-07
1- 4	1.3E-07	5.9E-07
5 -15	4.8E-08	1.9E-07
15-59	3.3E-08	1.2E-07
60 – 80	2.7E-08	1E-07

Table 4.93: Summary of Cancer Risks for Residential Population of Wang Phrao Village (Complete Sales)

Wang Phrao	for CTE	for RME
Age	Risk	Risk
0-1	4.9E-09	4.2E-08
1- 4	1.2E-07	4.6E-07
5 -15	4.3E-08	1.5E-07
15-59	2.8E-08	9.5E-08
60 – 80	2.4E-08	8.1E-08

Table 4.94: Summary of Cancer Risks for Residential Population of Sop Chang Village (Complete Sales)

Sop Chang	for CTE	for RME
Age	Risk	Risk
0-1	3.6E-09	2.4E-08
1- 4	4.5E-08	2.3E-07
5 -15	1.7E-08	7.8E-08
15-59	1.2E-08	4.8E-08
60 – 80	9.4E-09	4.1E-08

4.7.3.3 Utilization Population

There are also three groups of exposed populations in this scenario, namely, the truck drivers, the workers at ready-mix concrete plants, and concrete products end users. Exposure will be estimated based on interviewed information for each group of population. The possible routes of exposure are listed below:

Truck Drivers:	Dermal Contact and Inhalation
Workers at Ready-mix Concrete Plants:	Dermal Contact and Inhalation
Concrete Products Users:	Dermal Contact

With higher amount of fly ash sales, more truck drivers will come to the plant, and some drivers will have to come more often. They may have to wait longer, however, the fly ash loading process from silos will take about the same amount of time.

Larger amount of fly ash transported to ready mixed concrete plants leads to possible more mixing batches for ready mixed concrete. The same number of workers may have to be exposed to more inhalation of fly ash containing dust, resulting in higher risks.

The types of utilizations of fly ash concrete are reasonably unchanged as they depend largely on percentage of fly ash in concrete. More amount of sold fly ash, according to assumed complete sales, would lead to more distribution of utilization, especially to where fly ash ready mixed concrete business does not exist.

The summary of cancer risks for extrapolated complete sales of fly ash, is shown in Table 4.95 in the next page:

Table 4.95: Summary of Risks for Utilization Population (Complete Sale)

Utilization Scenario (Complete Sale)		Utilization Scenario (Complete Sale)	
Total Risk for CTE	Risk	Total Risk for RME	Risk
	-		-
Truck Drivers	3.1597E-09	Truck Drivers	5.90E-06
Workers (Ready Mixed Plants)	6.1245E-08	Workers (Ready Mixed Plants)	1.28E-06
End Users:		End Users:	
- General Structure	3.502E-10	- General Structure	1.381E-08
- Road Surface	2.6686E-10	- Road Surface	1.052E-08
- Special Structure	6.3468E-10	- Special Structure	2.503E-08

Within the utilization population, the magnitude of risks follows the same trend as those of current sale and storage scenario, all with acceptable range. According to Table 4.95, cancer risks in descending order are truck drivers, workers at ready mixed concrete plants, and end users, respectively.

Risk contribution of each pathway in all population groups is tabulated in Table 4.96 to Table 4.98 shown on the next page:

Table 4.96: Percent Contribution of Risk by Pathways (Occupational Population)

Occupational Population						
Pathways	Workers (plants)		Workers (storage)		Visitors	
	Risks	% Contribution	Risks	% Contribution	Risks	% Contribution
Ingestion	2.11E-07	10.48	1.82E-07	9.84	9.46E-09	15.45
Inhalation	1.80E-06	89.44	1.66E-06	89.92	5.14E-08	83.97
Dermal Contact	1.58E-09	0.08	4.39E-09	0.24	3.55E-10	0.58
	2.01E-06		1.85E-06		6.12E-08	

Table 4.97: Percent Contribution of Risk by Pathways (Residential Population)

Residential Population (drink river water)			Residential Population (do not drink river water)		
Pathways	Typical values		Pathways	Typical values	
	Risks	% Contribution		Risks	% Contribution
Ingestion (water)	7.72E-07	58.34	Ingestion (water)	0	0.00
Ingestion (fish)	5.11E-07	38.58	Ingestion (fish)	3.29E-08	51.88
DC (swim/shower)	2.58E-08	1.95	DC (swim/shower)	1.40E-08	22.09
DC (farming)	1.51E-08	1.14	DC (farming)	1.65E-08	26.03
	1.32E-06			6.34E-08	

Table 4.98: Percent Contribution of Risk by Pathways (Utilization Population)

Utilization Population						
Pathways	Truck Drivers		Workers (ready mixed plants)		Users (special structures)	
	Risks	% Contribution	Risks	% Contribution	Risks	% Contribution
Inhalation	3.99E-07	99.61	4.12E-08	89.68	-	0.00
DC	1.58E-09	0.39	4.74E-09	10.32	3.17E-10	100.00
	4.01E-07		4.59E-08		3.17E-10	

4.8 Results of RISK*ASSISTANT

Standard output of RISK*ASSISTANT for a group of population of Mae Moh Station village with certain exposure pathway is attached in Appendix G, while summarized results are listed in Table 4.99.

**Table 4.99: Results of Cancer Risks by
Manual Evaluation and RISK*ASSISTANT**

Pathway	Manual Result	RISK*ASSISTANT	% Difference
Water Ingestion (CTE)	1.7×10^{-6}	2×10^{-6}	17.6
Water Ingestion (RME)	4.47×10^{-6}	4×10^{-6}	10.5
Fish Ingestion	3.4×10^{-7}	4×10^{-7}	17.6

CHAPTER V

DISCUSSIONS

5.1 Introduction

This research aimed at quantifying risks associated with total arsenic in fly ash related to its possible utilization options: fly ash sale that resulted in utilization of fly ash as construction materials or the storage of fly ash at the dumping area, which may lead to possible contamination of surrounding area. The identified comparative site-specific risks would be used as a tool for risk management to lessen the degree of conflicts and disagreement between pro-utilization and anti-utilization groups in Thailand.

To achieve such aim, human health risk assessment was conducted within a designed framework of study in accordance with current United States Environmental Protection Agency (U.S. EPA) risk assessment guidance and recent scientific literature, as well as specific information necessary for this study. Central tendency exposure (CTE) and reasonable maximum exposure (RME) parameters were used to quantify exposures for occupational, residential, and utilization populations. In stead of a point estimation of risk, a range of values would be used to represent cancer risks. The range of risk values represents average risk and reasonably possible maximum risk an individual may expose to.

There are many variables and parameters that are essential for the health assessment. These values were either taken from credible secondary data sources or databases, directly determined by laboratory experiments, or obtained from a survey or personal interviews, as well as the expertise opinion and judgments. A number of conservative assumptions were used to evaluate exposures and risks for both CTE and RME. These assumptions may result in an overestimate of exposure, and consequently, risks. Background concentrations were also measured in order to determine additional or excess risks above background levels.

Total arsenic concentration measurement was done using Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS), with the detection limit of one (1) part per billion (ppb). This method is explained in more details in Chapter 3. Meanwhile, compressive strength tests were done using the Universal Testing Machine (UTM) following the American Society of Testing Materials Standard (ASTM) 109-90. More details are also explained in Chapter 3 of the thesis. In addition, RISK*ASSISTANT, a computer software package, was used to partly verify the results manually found.

Section 5.2 discusses about the evaluation of methods used throughout the thesis, while section 5.3 evaluates the results of research. Section 5.4 concerns about the limitations of the study.

5.2 Evaluation of Methods

All methods were designed to closely simulate the reality for the best assessment and evaluation of human health risk. There are a number of methods for evaluation: data sampling and collection, leaching tests, compressive strength tests, graphite furnace atomic absorption spectrophotometry (GFAAS) analysis, human health risk assessment processes, and an approximation of risk by RISK*ASSISTANT.

Data sampling was done using random sampling processes. The locations of sampling points were selected to be overall representatives of each medium. The quantity of samples was collected in adequate amount and preserved in accordance with proper laboratory procedures. A maximum value and an average of three samples from the same medium at the same location were used in the assessment for all tests and analysis.

An analysis by Graphite Furnace Atomic Absorption Spectrophotometry was done to determine total arsenic concentrations in different media, in this study, in water samples, soils samples, fly ash samples, and grass samples. Water samples required no digestion, while the others had to be digested before injecting into the machine. Three samples at one location were analyzed and the results of GFAAS analysis were shown in Table 4.5. The analysis can detect arsenic concentration down to a limit of 1 part per billion, however, it was more difficult and less reliable to

determine arsenic quantity at low concentrations due to the involved processes of the analysis.

Background concentrations were also analyzed by GFAAS for comparative analysis. Background samples were collected from the points unaffected by the chemical of concern. Three samples at each location were processed and analyzed for background concentrations.

The leaching tests were adapted from the U.S. EPA TCLP with determination of total arsenic concentrations by GFAAS. The samples being tested were fly ash-cement mortars with different percentage of fly ash by weight, with a control sample of pure cement mortars. Three (5 x 5 x 5) cm³ cubes were tested for each mixture of samples. The submerged water (28 days) and crushed samples were used to represent average and possible maximum leachate concentrations. Submerged water samples needed no digestion, while crushed samples of mortars had to be digested before further analysis by GFAAS. Concentration of non-detections were replaced by a detection limit of 1.0 part per billion.

The compressive strength tests were done according to the ASTM 109-90 to determine compressive strengths of fly ash-cement mortars at varying percentage of cement replacement by fly ash at different ages after casting. The test schedules are shown in Table 3.5 to Table 3.8, while the test results are shown in Table 4.8 to Table 4.11 and Figure 4.10. The results of the compressive strength tests were used as valuable information for human health risk assessment for utilization population. Three cubes of (5 x 5 x 5) cm³ were analyzed for compressive strengths by universal testing machine each sample. The results followed the trends pre expected; the higher percent cement replacement, the lower initial compressive strengths the mortars would yield. After a certain period of time, compressive strengths of all mixtures would yield approximately the same ultimate strength. For long term consideration, fly ash mortars could yield even higher ultimate compressive strength than pure cement mortars.

Assessment of human health risks was done in accordance with the U.S. EPA guidance with as much site-specific information as possible. Many phases were completed in order and sometimes simultaneously. Data collection and evaluation were one of the first tasks in the assessment. Exposure assessment emphasized on

identifying and quantifying intakes in different pathways, which later led to risks. Toxicity assessment was used as basis information and international databases, especially in this situation with lacking local or region toxicity factors. While, risk characterization served as the link theoretical results and practical risk management by comparing quantity of risks from exposure assessment and their extrapolation to human health. As much information as possible was obtained to fit in the necessary steps in all phases in the human health risk assessment.

RISK*ASSISTANT software package provided quick quantification of human health risks. Many features of the package were easy to use and can be applied or adapted to most environmental settings, however, in some scenarios in the study, RISK*ASSISTANT may not have appropriately simulated the actual situations. A good example was that the quantification of RISK*ASSISTANT was based on a different set of equations from U.S. EPA guidance manual, although the databases sources were the same. A number of unchangeable parameters were different from reality of specific site, for example, actual percentage of total arsenic concentration in fish cannot be directly entered into the software.

Because of the reasons above, results from manual risk assessment were slightly different than those obtained by RISK*ASSISTANT, in the range of 10.5 – 17.6 percent of deviation (Table 4.99). The slope factors used in the 2 methods were the same. However, the values of intakes made a difference for total pathway cancer risks.

In this case, human health risk assessment manually done in accordance with U.S. EPA manual better simulated the real and specific situation and thus resulted in more appropriate values of risks of risk, while the use of RISK*ASSISTANT was a very useful and convenient means to closely and quickly get an approximate magnitude of the overall results. It is proven that RISK*ASSISTANT is a useful, quick and easy-to-use software package suitable for certain scenarios for quick risk evaluation. However, in this particular study, RISK*ASSISTANT may not be appropriate to approximate the results, and thus in this study it is used to partly verify manual results of the assessment, especially with highest risks for residential and occupational populations.

5.3 Evaluation of Results

The overall results showed that all cancer risks in all scenarios and populations were within acceptable limits by international standard established by the U.S. EPA (Tables in Chapter 4) with some confidence/ assurance. In this particular study with certain chemical of concern (arsenic) and environmental settings, no problem is of special concern. Legally, no remedial actions or processes are required.

Highest cancer risks for all populations were associated with complete sale of fly ash and reasonable maximum exposure:

Highest cancer risk for residential population:	1.70×10^{-5}
Highest cancer risk for occupational population:	1.01×10^{-5}
Highest cancer risk for utilization population:	5.9×10^{-6}

Highest cancer risks for residential, occupational, and utilization populations are 17%, 10.1%, and 5.9% of allowable value of 10^{-4} , respectively.

Background concentrations are listed in Table 4.6 and plotted in Figure 4.8. These concentrations were used as the bases of natural occurrence risks. Additional risks over background will be further quantified and characterized. The background concentrations of arsenic in river water, unaffected by the Mae Chang River, were quite diverse and no trends or correlation could be determined. The nature of basement rocks and soils in different locations yield widely different values with large range of natural occurrence. The difference in values of background arsenic concentrations was typically normal.

Different populations are subject to different exposure pathways according to the overall site models in Figure 4.1. Each exposure pathway contributes to certain degree of the total risks, depending on the exposure activities and exposed concentrations. Two comparative analyses can be discussed about the risk contributions from different exposure pathways and populations. One is the comparative magnitude of risk across the population groups, while the other is a contribution of risk within the same population group via different exposure routes.

According to Table 4.96 to Table 4.98, we can numerically compare risks across population groups. The utilization group had the lowest risks of all population, followed by residential population and occupational population had relatively highest

risk among all groups. All risks did not exceed the limit of 10^{-4} risk. This is due to the nature of exposure activity and pathways, and contaminant concentration for each population. Low arsenic leachate concentration and fewer hours of exposure led to relative lower risks than other groups. While, occupational population had more rigorous working hours with even higher inhaled arsenic concentration, thus resulted in much higher risks, up to about two orders of magnitude.

For utilization population (Table 4.98), concrete product end users, general construction workers, road surface workers, and special purpose structure workers, had the lowest risks in this population, with the only pathway being dermal contact. Truck drivers had the highest risks in this group, up to two orders of magnitude of those of end users, with inhalation exposure as predominant route, contributing more than 99% of total risks. This is due to the more rigorous work hours of the truck drivers while exposing to relatively high arsenic concentration in air and that inhalation is a more sensitive route of exposure than dermal contact exposure. Estimated risks for workers at ready mixed concrete plants yielded values somewhere in between those of truck drivers and concrete products end users. Inhalation also contributed a major portion with almost 90% of total risks.

For residential population (Table 4.97), one factor differentiates the overall risk in this group, the drinking water pattern. Out of 27 villages along the Mae Chang River, 4 villages drink from the Mae Chang River. Typical risks from these 4 villages were much higher than those from the other 23 villages. Ingestion of water contributed a majority, almost 60%, of total risks for the 4 villages, while ingestion of fish came second, with almost 40%, and dermal contact from swimming, showering, and farming activities contributed very little to the overall risks. Direct ingestion of arsenic in water or fish would lead to higher chance of absorption due to the nature of exposure route. Typical risks from water ingestion alone were higher than total risks for all utilization population risks and total residential population risks of those villages that do not drink from river water. It is also kept in consideration that people who drink from river water only make up a small portion of the whole village. Approximately 10 to 30 households in each village live along the Mae Change River and drink from it. The further the distance away from the river, the less opportunity of water utilization, especially for the drinking exposure.

For occupational population (Table 4.96), the potentially highest risk groups were workers at plant units 4-13, with inhalation as the primary contributing route of exposure with approximately 90% contribution. Incidental ingestion contributed about 10% while dermal contact is very minimal for these people. Workers at storage site were subject to little lower risks than workers at plant units, with about the same proportion of contribution of each exposure route. Visitors, who spent less time exposing to arsenic, were resulted in somewhat lower risks, 1 – 2 orders of magnitude lower. Inhalation also contributed the majority of total risk with more than 80%. In this particular population, risks resulted from inhalation exposure predominates others because of the population typical work patterns. The population is subject to little risks from the incidental ingestion.

It is also noted that all populations are not totally separated. Small group of people may belong to more than one population. For example, occupational workers at plant units or storage site may be a part of residential population when they stay at home while not working. For this special group of population, all exposure parameters would all have to be reconsidered. Resulting risks may be higher than those of occupational population, but would be no more than the combination of risks of the two populations, which in this case, remained less than allowable limits for cancer risks. It is also noted to keep in mind cancer risks resulting from inhalation pathway that were not quantified due to lack of the inhalation slope factor. Such risks may contribute to an accumulation of total risks.

Relatively high risk groups are worth further discussions on how such risks may be reduced. Although these people are not facing with critical risks, it is important to emphasize any possible risk prevention and/or reduction in the communities, especially with the long plant operation expectancy of over 50 years.

A group of population in Mae Moh Station village was evaluated to have the highest cancer risks in residential population. Focusing on exposure pathways mentioned previously, the total cancer risks could be reduced primarily by reducing ingestion of river water and if possible less ingestion of fish. While, workers in Mae Moh plant units 4 – 13 were the highest risk group in occupational population. These workers would face with drastically lower risks if they prevented themselves from

arsenic intakes via inhalation exposure, perhaps by wearing protective masks or spending less time in area of high dust concentration.

In the processes of human health risk assessment, many steps have to be taken to determine and quantify final risk range or values. Many parameters had to be measured or estimated with the best possible means available. The final results were represented by ranges of values for average and reasonable maximum cancer risks for each scenario, group of population, and age of individual receptors. The same trends were observed for the same situation with the same scenario, i.e. same village with different scenarios.

Besides, measured values from laboratory testing, many factors affected the results of cancer risks. It is evident that there are many variables in intake and risk formulas, with different degree of influence.

Cancer risks are calculated by multiplying intake by cancer slope factor, a pre-determined value set by the U.S. EPA. Because cancer slopes are 'built-in' values, therefore, it is necessary to look at how values for intakes are assigned by examining the formulas.

Variables in formulas of intakes for all exposure pathways are considered. Pathway-specific variables in the intake formulas are the concentrations of arsenic in medium, contact rate (swimming), skin surface area and dermal permeability constant (farming), ingestion rate and fraction ingested from contaminated sources (incidental ingestion and ingestion of fish), soil to skin adherence factor and absorption factor (dermal contact to fly ash). While, common variables about receptors are exposure frequency and duration, body weight and averaging time.

In the calculation all factors, both numerators and denominators, have the same degree of influence to the total intake, i.e. all have the first-degree influence. For example doubling the value of any numerator (such as arsenic concentration) will double the total intake and thus the risk, while doubling any denominator (such as body weight) will cut the intake and risk by 50%, given that all others values are held constant. If any denominator is missing, i.e. has the value of zero, the total intake and risk also do not exist, no matter what the values of others are. For example, for water ingestion pathway, risks only exist with the only 4 villages that have values of ingestion rates of drinking water.

Occasionally equations require parameters that are site specific and no study has been done to determine such parameters. Therefore, best estimate by interviews would be the only and most suitable solution. For instance, information on ingestion of water and fish for residential population assessment was never recorded. Frequency and duration of exposures to different pathways were also never documented. These called for interviews of population for all possible exposure pathways variables that were missing.

It is noted in Figure 4.7 that there was high correlation, with a coefficient of 0.901, or a highly positive link between total arsenic concentration in the Mae Change River and the distance along the river from discharge points at the Mae Moh reservoir. Generally speaking, the further away from Mae Moh reservoir along the river, the lower concentration of total arsenic could be expected. In other words, concentrations of total arsenic in water dissipated along the length of the river.

The Concentration of total arsenic in river water is one important factor that influenced the total risks of those people who regularly drink from the river. However, total risks also depend on many other factors, such as exposure frequency and duration, the body weight of a receptor, as well as background concentrations. To assess an overall risk, one is required to consider all influencing factors. A careful consideration of risk equations may be helpful for the assessment.

Results from RISK*ASSISTANT software package yielded some small deviations from manual assessment of human health risk. However, reasons mentioned previously supported that manual results are more suitable for this study. However, in many scenarios, RISK*ASSISTANT was useful to quickly determine risk values, especially for feasibility study or preliminary investigations of certain environmental settings. It helps save time and budget and provides assessors with a good idea of total risk for such scenario.

A complete study was done to investigate Mae Moh Lignite Power Plant operation and its effect on the surrounding environment, especially the populations that are associated with the processes and/or results of the operation. One important subject is critical to the planning and the projected operation of the plant, the carrying capacity of the area. Although the Power Plant owns an area of more than 100,000 rais, a large portion is separated and distant from the plant units. The plant units are

located in relatively small area surrounded by mountains and water bodies, both natural and man-made.

The carrying capacity of the area depends on many factors, such as Mae Moh site-specific physiographical and geological settings, climate, temperature, wind, and soils conditions. It is a maximum level that the environment can locally undertake a degree of intensity or volume of degradation, which should not be exceeded. The localized carrying capacity is basically a threshold level for the environment in absorbed media, such as air, water, and soils. Therefore, an intensive study should be done to determine and understand the carrying capacity of the Mae Moh site to ensure the sustainable operation of the plant throughout its live expectancy. The study should include scenarios of possible incidents, including the natural occurrence such as heavy rains and storms, or human errors that could result in small deficiency to a collapse of some operating systems of the plant.

Long-term consideration of plant discharge such as concentrations of emitted gases and treated water is an important issue to ensure sustainable future plant operations. Nevertheless, an economic aspect also has to be emphasized. Lower emitted concentrations may call for better technology and thus higher cost of operation, while current emissions comply with national regulations and the risks assessed fall within international allowable limits. With no current obligation for remedial actions, a balance between cost of operation and emission to the environment needs to be carefully considered for the future of the plant operation. The long-term operation of the plant has to be environmentally friendly and economically practical.

5.4 Limitations and Uncertainty

Evaluating areas of uncertainty in risk assessment is crucial to the understanding of overall reliability of the assessment conclusions. Areas of uncertainty are associated with sample collection, data evaluation to include laboratory analysis, estimation of potential exposures in exposure assessment, toxicity assessment, and risk characterization. These uncertainties may result in either an over or under estimation of risks. However, for this study, where uncertainties exist, a

conservative approach was taken where appropriate. The risks are more likely to be over-estimated rather than under-estimated.

Highly quantitative statistical uncertainty analysis is usually not practical or necessary for risk assessment sites due to a number of reasons. The resource is required to collect and analyze site data in such a way that the results can be presented as valid probability distributions. It is also already known that in all environmental risk assessments, uncertainty about the numerical results is generally large, in a range of an order of magnitude or greater (U.S. EPA, 1989). Consequently, it is more important to identify the key site-related variables and assumptions that contribute to the uncertainty than to precisely quantify the degree of uncertainty in risk assessment.

There is uncertainty associated with the analytical data for sampled water, soils, fly ash, and grasses, which are used as critical site-specific parameters in the calculation of intake values in the exposure assessment. There are inherent assumptions, both practically and statistically, that the sample analyzed are adequately representative of all possible areas, which could have been sampled.

Temporal differences make sampling procedures more complicated. Summer and rainy seasons are quite different in nature, and thus conditions of media also vary. Temperature and amount of precipitation are important variables that cause difference of measured concentration in each medium of concern.

Relying on secondary data for some parameters also leads to some degree of uncertainty. Secondary data are used as least as possible to replace some parameters not available by other means.

Laboratory works may involve uncertainties in the testing and evaluation processes. In the processes of Graphite Furnace Atomic Absorption Spectrophotometry (GFAAS) analysis, compressive strength tests, and leaching tests, precision and accuracy both of machines and humans are limited, thus result in some degree of uncertainty. These uncertainties are relatively small compared to other sources of risk assessment procedures.

In the exposure assessment, variability is inherent in the default exposure parameters used in the intake equations due to lack of site-specific data. These default exposures are meant to broadly represent what are assumed to be typical scenarios

among the different exposure pathways, and so may differ from actual conditions at the subject site.

Assumptions about the use of these defaults are based on knowledge of typical circumstances at a broad range of contaminated sites. Final risk estimates are heavily based on information from interviews. Although interviews were done with proper statistics bases, the information may not completely represent the whole population. A large sampling of interviewed group and quantification risks in ranges of values are used to reduce the degree of uncertainty in this case. In addition, assigning a value of the detection limit to appropriate non-detections of arsenic concentration contributes some uncertainty to data representativeness. Sample sizes selected for each medium are above the regulatory minimum requirement.

In toxicity assessment, a degree of uncertainty is quantified to a certain extent, as illustrated by the noncarcinogenic RfC/RfD uncertainty factors used in IRIS to designate relative credibility of the different toxicity factors, to include those of carcinogenic factors. All of uncertainty factors, i.e., variation among human populations, extrapolation of animal study results to humans, extrapolation of lowest observed adverse effect levels (LOAELs) from no observed adverse effect levels (NOAELs), extrapolation of chronic effects from subchronic studies, and alternative methods of toxicity value estimation all contribute to the overall uncertainty in the toxicity assessment.

Toxicity factors, even if approved by a review committee, have an inherent uncertainty because they are usually obtained through animal toxicity studies and extrapolated for use in human health evaluation. Therefore, there is some degree of uncertainty associated with the toxicity factors used in the human health risk assessment.

Risk characterization is very important step of the human health risk assessment because it serves as a bridge between risk assessment and risk assessment. It is important that major assumptions, scientific judgments, and estimates are done reasonably.

In general, aspects of the risk characterization phase of risk assessment that can introduce uncertainties into the risk assessment results include the validity of adding

carcinogenic risk estimates for multiple chemicals and the validity of adding carcinogenic risk estimates across exposure pathways.

Because this assessment focused only on arsenic, it does not include uncertainties associated with adding risk estimates calculated for multiple chemicals. The risks posed by a chemical (arsenic) following exposure via different pathways may differ in ways that are not adequately reflected by simple addition of risk estimates derived for each individual pathway. Also, when interpreting the results from combining risk estimates for different exposure pathways, the likelihood that such combinations of pathways or scenarios will occur must be considered.

Risk assessment methods are designed to be conservative to address the uncertainties associated with each step in the process. Thus, actual risks are not likely to be greater than risks estimated using standard risk assessment methods. Key factors that are likely to overestimate rather than underestimate the final risks are:

- Using the reasonable maximum (RME) exposure parameters
- Assuming 30 – 70 years of exposures
- Assuming arsenic concentrations in water do not decrease before ingestion
- Assuming the same mechanisms for humans of all ages
- Assuming that the dose-response relationship for arsenic is linear at low doses and addition of risks across pathways is legitimate

U.S. EPA (1992) also classified uncertainties into 3 types: scenario uncertainty regarding missing or incomplete information needed to fully define the exposure and dose; parameter uncertainty regarding measurement, sampling, variability and use of generic or surrogate data; and model uncertainty regarding gaps in scientific theory required to make predictions on the basis of casual inferences.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Considering the results obtained from this study, the following conclusions can be drawn:

- It was found that the Mae Moh Lignite Power Plant posed some additional human health risks to background level. A high linear correlation coefficient of 0.9 was found from the plot of total arsenic concentration and the distance along the river, away from the treated water discharge point from the plant. Necessary information was collected and human health risks were then assessed for different modeled scenarios.
- Human cancer risks associated with total arsenic in fly ash due to current plant's practice (a portion of fly ash sale and storage) of Mae Moh Lignite Power Plant was assessed in accordance with the United States Environmental Protection Agency's (U.S. EPA) guidance manual. The resultant cancer risks were within international standards set by the U.S. EPA for all populations.
- Human cancer risks associated with total arsenic in fly ash due to modeled extrapolated complete storage of fly ash (all fly ash is transported to storage site) of Mae Moh Lignite Power Plant was assessed in accordance with the United States Environmental Protection Agency's (U.S. EPA) guidance manual. The resultant cancer risks were within international standards set by the U.S. EPA for all populations. The risks were determined to be approximately 30 percent lower than those of the current practice scenario.
- Human cancer risks associated with total arsenic in fly ash due to modeled extrapolated complete sale of fly ash (all fly ash is sold to buyers for utilizations) of Mae Moh Lignite Power Plant was assessed in accordance with the United States Environmental Protection Agency's (U.S. EPA) guidance manual. The resultant

cancer risks were also within international standards set by the U.S. EPA for all populations. The risks were determined to be approximately 20 percent higher than those of the current practice scenario.

- Human cancer risks associated with total arsenic in fly ash due to modeled extrapolated complete sale of fly ash (all fly ash is sold to buyers for utilizations) of Mae Moh Lignite Power Plant was calculated using RISK*ASSISTANT software package for certain exposures and selected population. The resultant cancer risks were within international standards set by the U.S. EPA for all populations, although the results were slightly different from those obtained from the manual evaluation.

- The research hypothesis that the overall human health risk due to toxicity of total arsenic when fly ash is utilized as construction materials is less than that resulting from toxicity due to the storage of fly ash was invalid. The results of this study showed that the overall human health cancer risks due to total arsenic as a result of utilization of fly ash is approximately 50 percent greater than that resulting from storing fly ash.

- Although the utilization of fly ash as construction materials, especially as an additional aggregate to replace cement in ready mixed concrete, will be projected to cause higher risks to human health than does the current practice, the total cancer risks were determined to be only slightly higher and remained within acceptable limits. Considering other aspects such as economic incentives of the plant and other businesses, as well as, an environmental benefit of one-ton CO₂ reduction by decreasing of a ton of cement produced, fly ash may be utilized as construction materials with careful preventive plans and actions such as proper monitoring and regular follow-ups of emissions and discharge.

- The Compressive Strength Test and Leaching Test, together, indicated that up to approximately 30 percent of fly ash, with no admixtures, may be practically and safely used to replace cement in construction materials. End users may need to translate percent by weight to percent by volume for actual applications.

- The residential and occupational population were determined to have higher risks than utilization population. Villagers with river water ingestion were the highest risk group in the residential population, while truck drivers were exposed to the highest risks of the occupational population. Water ingestion and inhalation were

the highest risk contributing pathways for the two groups of populations, and thus they represent the high risk ‘zoning’ population, while remaining within acceptable ranges of cancer risks.

6.2 Recommendations

According to the overall processed framework of this study, especially the methodology and results, the following recommendations for future studies can be drawn:

Future studies should be extended to cover the following areas:

- an investigation of other potential chemicals of concern (CoC's)
- a determination of total inorganic arsenic, which is much more toxic to human beings than organic arsenic. Results of laboratory experiment will be used to refine the current study's results.
- a speciation of inorganic arsenic, arsenite-As(III) and arsenate-As(V)
- a verification of the study by analyzing information from local hospitals.
- a search for and screen out of other possible sources of arsenic, which may be discharged into Mae Moh Reservoir resulting in excess arsenic.
- an economic and social aspects and analysis for all other possible scenarios.
- an assessment of more intensive data collection with temporal deviations.
- an attempt to reduce degree of uncertainty presented in Section 5.4.
- a complete human life cycle, possibly the ingestion of food and beverages.
- an analysis of chemical and risk transportation from sources.
- an overall ecological assessment of repeated scenarios.
- an investigation of other environmental models that may be more suitable for this situation.

Recommendations are also laid out for the relevant parties to the study, the Mae Moh Lignite Power Plant and the exposed populations. Recommendations for the Power Plant are followed in the next page:

Part of the Power Plant's revenue may be utilized and invested in many ways in the long run, for instance:

- look forward to the risk management of future operation. Keep good record of planned monitoring and appropriate follow-ups for all environmental indicators.
- provide risk education programs for occupational and residential communities and population who are and potentially at risks, as well as, to reinforce safety rules and regulations for all workers at the plant.
- provide clean drinking water free of charge at a convenient pick-up point, and at low cost for people who need delivery, especially those who drink from river water and those who live within close proximity.
- look for possible alternative sources of power and/or better quality of coal.
- aim at higher efficiency of water and air treatment system.
- provide mobile health check-up units free of charge for population in affected villages at reasonable period.

While, recommendations for exposed population are as follow:

- understand the ways to lower intakes, which resulted in reduced risks. Make an appropriate modification to daily activities such as drinking from alternative sources of water.
- stay alert and participate in social activities provided by the communities and the Electricity Generating Authority of Thailand.
- usual check up at hospitals at reasonable frequency recommended by proper medical staff.

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รายชื่อลูกค้าที่ซื้อเก้าอี้จากโครงการจัดการธุรกิจวัตถุพลอยได้ โรงไฟฟ้าแม่เมาะ

ลำดับที่	รหัส	ลูกค้า	โทรศัพท์	โทรสาร
1.	001	บจก. ผลิตภัณฑ์และวัตถุก่อสร้าง	0-2555 - 5386	0-2587 - 0168
2.	002	บจก. ชิกม่าคอนกรีต	0-2273 - 0032 ต่อ 307	0-2273 - 0706
3.	006	บจก. ไทยแซค	0-5385 - 2110 ถึง 1	0-5385 - 2344
4.	007	บจก. เพ็ญอรุณ	0-5665 - 0799 ถึง 800	0-5661 - 1383
5.	009	บจก. น้ำแข็งคอนกรีต (1992)	0-2295 - 0901 ถึง 10	0-2295 - 3122
6.	010	บจก. นครหลวงคอนกรีต	0-2272 - 5555	0-2615 - 7008
7.	012	นายมนตรี บัดตพงศ์	0-5529 - 8609 ถึง 611	0-5529 - 8609 ถึง 611
8.	013	บจก. ทีพีไอ คอนกรีต	0-2678 - 5350 ถึง 74	0-2678 - 5376 ถึง 8
9.	014	บจก. ซี. เอส. บี. สติลเวอร์ค	0-2613 - 6619 ถึง 20	0-2214 - 2850
10.	019	บจก. ชลประทานคอนกรีต	0-2318 - 7111	0-2319 - 8267
11.	022	บจก. โออาร์ซี พรีเมียร์	0-2559 - 1021 ถึง 3	0-2559 - 1020
12.	028	บมจ. อิตาเลียนไทยฯ	0-2716 - 1600	0-2716 - 1519
13.	029	หจก. เอ็ม. พี. เอส. เอ็นจิเนียริง	0-5426 - 6178	0-5426 - 6178
14.	030	บจก. พี. เอ. คอนกรีต	0-5422 - 2858 ถึง 9	0-5422 - 2801
15.	036	บจก. นอร์ทเทิร์น แมททีเรียล	0-1602 - 0594, 0-5421 - 4107 ถึง 8	0-5421 - 4108
16.	051	หจก. วงศธรคอนกรีต	0-5381 - 2816	0-5381 - 2816
17.	053	บจก. เอเชียผลิตภัณฑ์ซีเมนต์	0-2641 - 5600 ถึง 79	0-2641 - 5694
18.	054	หจก. มังกรทองคอนกรีต	0-5666 - 2165 ถึง 6	0-5666 - 2166
19.	059	บจก. ทอรัสพอซโซลานซ์	0-2559 - 2318 ถึง 21	0-2559 - 2322
20.	061	บจก. ดีคอนโปรดักส์	0-2937 - 3312 ถึง 7	0-2937 - 3328
21.	065	บจก. กิตติพงษ์ ไม่นิ่ง	0-3636 - 0134 ถึง 9	0-3636 - 0140
22.	066	บจก. ฟาลังซ์	0-2320 - 1546 ถึง 7	0-2721 - 5634
23.	067	บจก. ผลิตภัณฑ์คอนกรีตชลบุรี	0-3828 - 5440 ถึง 1	0-3827 - 5894
24.	070	หจก. แกรนด์ ไมเดส	0-2934 - 7030	0-2934 - 7030
25.	077	บจก. ไทยพีค่อนและอุตสาหกรรม	0-2640 - 0285 ถึง 6	0-2246 - 4568
26.	080	หจก. บ้านตาลอุตสาหกรรม	0-7537 - 7504 ถึง 6	0-7537 - 7506
27.	081	บจก. ทาการ่าโฮม	0-2533 - 3645	0-2533 - 3816
28.	083	หจก. มาตรฐานพัฒนาวิศวกรรม	0-1601 - 3998	0-4334 - 4918

ลำดับที่	รหัส	ลูกค้า	โทรศัพท์	โทรสาร
29.	098	บจก. พิบูลย์คอนกรีต	0-5384 - 9435 ถึง 8	0-5384 - 9439
30.	105	บจก. 501 ซีวิล แอนด์ ดีไซน์	0-2509 - 3193	0-2936 - 8172
31.	107	บจก. แอล. พี. ซี. อินดัสเทรียล	0-5354 - 1267 ถึง 8	0-5354 - 1429
32.	108	หจก. สิทธิพรการยาง	0-3564 - 4432	0-3561 - 1352
33.	109	นายกฤษณะ เจริญพานิช	0-1883 - 1304, 0-5422 - 6495	-
34.	110	บจก. แชนสัน คอนกรีต (ประเทศไทย)	0-2390 - 0240	0-2390 - 0241
35.	117	บจก. ศิริชนาวิวัฒน์	0-2947 - 4772 ถึง 3	0-2947 - 4774
36.	118	หจก. สุขเจริญคอนกรีต	0-2921 - 9125 ถึง 8	0-2921 - 9126
37.	119	นายสมเกียรติ เมัยกานัด	0-1039 - 4680	-
38.	121	หจก. ลำปางนิพนธ์บริการ	0-5427 - 1500 ต่อ 2681	0-5427 - 1500 ต่อ 2681
39.	132	หจก. ตระกูลพาณิชย์มุกดาหารฯ	0-4249-1001	0-4249-1001
40.	136	บจก. สานนท์ ขนส่ง	~~0-5435-1267~~ 036 - 351-004	
41.	137	บจก. โกลด์ ฟลาย แอช	0-2240-2696 ถึง 7	0-2240-2698
42.	138	บจก. เอชวีขนส่ง	0-2947-3877 ถึง 79	0-2947-3880
43.	139	บจก. ทู. เอส. พี. อินเตอร์เทรด	0-2399-0262	0-2393-9415
44.	140	หจก. สกลนคร วาย. ดี. ซี.	0-2918-3288	0-2918-3288
45.	141	บจก. ธรรมรัตน์คอนกรีต	0-5571-2035	0-5571-2005
46.	142	บมจ. ปูนซีเมนต์นครหลวง	0-2272-5555 ต่อ 4856	0-2272-5555 ต่อ 4594
47.	073	บจก. สามัคคีผลิตภัณฑ์คอนกรีต	0-2952-0729 ถึง 32	0-2952-0729 ถึง 32

รายชื่อบริษัท/ห้างฯ ที่รับขนส่งเข้าล้อย

ลำดับที่	บริษัท/ห้าง	ที่อยู่	รับขนส่ง	ขาย	Know-how	โทรศัพท์	โทรสาร
1.	บจก. ซี. เอส. บี. สตีลเวอร์ค	กทม.	/	/	-	02-6136619 - 20	02-2142850
2.	บจก. ทอรัสทอชโซลานซ์	กทม.	/	/	/	02-5592318 - 21	02-5592322
3.	บจก. ฟาลังซ์	กทม.	/	/	/	02-3201546 - 7	02-7215634
4.	นจก. แกรนต์ไมแมตส์	กทม.	/	/	/	02-9409542 - 3	02-9409545
5.	นจก. บุญประเสริฐสุโขทัย	เชียงใหม่	/	-	-	053-247760	053-247497
6.	บจก. เค. เอ็น. อาร์. กรุ๊ป	กทม.	/	-	-	02-6136619 - 20	02-2142850
7.	บจก. เอกรัฐโปรดักส์	ลำปาง / กทม.	/	-	-	054-361083, 02-5192299,5195044-9	-
8.	นจก. นครปฐมยนต์ภัณฑ์	ลำปาง	/	-	-	054-352811	054-352811
9.	นจก. รัชโยธินทรานสปอร์ต	สระบุรี	/	-	-	036-333579	-
10.	นจก. นครสวรรค์ดีประเสริฐ	นครสวรรค์	/	-	-	056-320354 - 5	056-320355
11.	บจก. เอแอนด์เอฟมอเตอร์เวิร์ค	ปทุมธานี	/	-	-	02-9010491 - 2	02-9010490
12.	บจก. เอียเป็งเชียง	กทม.	/	-	-	02-3683071 - 2, 7360400 - 2	02-3683073
13.	นจก. เพชรหมื่นรุ่งเรือง	สระบุรี	/	-	-	036-211123	036-221437
14.	นางสาวอาทิตย์ทิรา กระแฉ่ม	ราชบุรี	/	-	-	032-344271	032-344269
15.	บจก. ออโต้ทริกเซอร์วิส	สระบุรี	/	-	-	036-337106 - 7	036-337108
16.	บจก. ส.วิไลพาณิชย์คอนสตรัคชั่น	ฉะเชิงเทรา	/	-	-	038-836292	038-836687
17.	นจก. กริชชัยคอนสตรัคชั่น	กทม.	/	-	-	02-5333645	02-5333816
18.	บจก. ดิวิโซคลิง	กทม.	/	-	-	02-6400285 - 6	02-2464568
19.	บจก. ซีเมนต์ทรานสปอร์ต	อุดรธานี	/	-	-	042-240840, 01-9091501	042-240842
20.	บจก. พี. เอ. คอนกรีต	ลำปาง	/	/	/	054-222858	054-222801
21.	นจก. วุฒิชัยทรานสปอร์ต	นครสวรรค์	/	-	-	01-4750884	01-4757216
22.	บจก. จัมโบ้ทรานสปอร์ต	สระบุรี	/	-	-	036-332572	036-333645
23.	บจก. อาร์ แอนด์ เอฟ ทรานสปอร์ต	กทม.	/	-	-	02-9010491 - 2	02-9010490



ผลการตรวจวัดฝุ่น PM10 ของโรงงานคอนกรีตผสมเสร็จซีแพค			
ภาค	โรงงาน	ผลปี 2545	ผลปี 2546
		มาตรฐาน $\leq 0.12 \text{ mg/m}^3$	
กทม. & ปริมณฑล	1. เขียวหวานใหญ่	0.06	0.06
	2. บางพลี	0.12	0.08
	3. คลาย	0.06	0.07
	4. รัตนธิเบศร์	0.06	0.09
	5. คลังชั้น	0.06	0.11
	6. ปากน้ำ	0.09	0.11
	7. บางปู	0.06	0.06
ภาคตะวันออก	1. จันทบุรี	ปี 45 ไม่มีการตรวจวัด	0.06
	2. แกลง		0.11
	3. เขาวง		0.11
ภาคตะวันตก	1. พุทธมณฑลสาย 7	0.11	0.10
	2. สมุทรสาคร	0.08	0.06
	3. คลังเพชรบุรี	0.06	0.04
ภาคเหนือ	1. ลำปาง	0.03	0.09
	2. นครสวรรค์	0.09	0.11
ภาคอีสาน	1. หนองคาย	0.11	0.11
	2. อุบล-วาริน	0.05	0.11
	3. สกลนคร	0.07	0.07
ภาคใต้	1. ทุ่งสง	0.08	0.08
	2. ตรัง	0.07	0.04
	3. สงขลา	0.09	0.09



สรุปบัญชีข้อมูลประชากรเลขประจำหมู่บ้าน 1 ปีงบประมาณ 2548 งวดที่ 1

สำนักงานสาธารณสุขอำเภอแม่เมาะ

บัญชี	รวม	รวม		อพยพแม่เมาะ		ทำดี		น่าน		ใหม่		สบเปือย		ทาน		ตชช	
		ชาย	หญิง	ชาย	หญิง	ชาย	หญิง	ชาย	หญิง	ชาย	หญิง	ชาย	หญิง	ชาย	หญิง	ชาย	หญิง
อายุ 0-1 ปี	348	174	174	58	55	21	21	6	24	33	37	39	23	10	7	7	7
อายุ 1-4 ปี	1,576	824	752	320	277	101	71	53	63	149	138	140	139	42	42	19	22
อายุ 5-9 ปี	2,767	1,413	1,354	610	574	115	109	126	133	231	239	234	212	76	66	21	21
อายุ 10-14 ปี	3,001	1,526	1,475	593	577	121	145	161	176	264	234	284	229	88	95	16	19
อายุ 15-19 ปี	3,090	1,575	1,515	634	637	138	119	171	152	283	259	221	237	76	71	62	40
อายุ 20-24 ปี	3,106	1,516	1,590	640	598	136	166	140	127	273	315	195	254	82	84	60	46
อายุ 25-29 ปี	3,387	1,668	1,719	625	724	161	170	188	176	278	307	282	253	97	60	37	29
อายุ 30-34 ปี	3,603	1,795	1,808	693	754	189	176	177	186	325	286	284	294	89	82	38	30
อายุ 35-39 ปี	3,571	1,816	1,755	760	784	180	148	203	182	306	278	305	279	68	55	24	29
อายุ 40-44 ปี	3,346	1,692	1,654	757	790	155	128	152	142	276	261	264	240	67	61	21	32
อายุ 45-49 ปี	2,810	1,527	1,283	656	630	156	103	151	122	262	193	217	183	55	27	30	26
อายุ 50-54 ปี	1,919	1,018	901	447	407	91	77	101	93	182	147	130	128	36	32	31	17
อายุ 55-59 ปี	1,141	616	525	281	227	64	65	66	52	85	72	94	81	17	21	19	17
อายุ 60-64 ปี	1,178	633	545	284	236	64	69	79	64	86	82	96	70	14	21	10	3
อายุ 65-69 ปี	1,064	557	507	243	242	65	56	49	47	92	66	87	75	15	12	6	9
อายุ 70-74 ปี	777	376	401	153	162	44	42	47	44	51	62	65	71	10	12	6	9
อายุ 75-79 ปี	408	211	197	82	83	23	25	22	27	39	30	35	24	5	5	5	3
อายุ 80 ปี	451	225	226	100	105	15	19	17	26	50	42	29	22	5	5	9	7
ประชากรทั้งหมด	37,543	18,162	18,381	7,926	7,862	1,819	1,699	1,899	1,836	3,265	3,048	3,001	2,814	852	758	400	364
ประชากรทั้งหมด(ชาย+หญิง)	37,543	37,543		15,788		3,518		3,735		6,313		5,815		1,610		764	

The seal of Mahidol University is a circular emblem. It features a central blue circle containing a golden chakra (a five-spoked wheel) with a flame-like design. Above the chakra is a golden stupa (a tiered Buddhist monument). The entire central design is set against a light blue background. Surrounding this is a golden ring with Thai script. The top part of the ring reads 'จุฬาลงกรณ์' (Chulalongkorn) and 'มหาวิทยาลัย' (Mahavithayalai). The bottom part of the ring reads 'มหาวิทยาลัยมหิดล' (Mahidol University).

APPENDIX D:
Summary of Interviewed Information

Village: Hang Hung/Mae Moh (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming	DC @ Swimming/ Showering	Ingestion @ drinking water	Ingestion @ eating fish
0-1	6	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	30	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	163	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday : Interview	NO :Interview	YES :Interview
15-59	828	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally : Interview	NO :Interview	YES :Interview
60-80	106	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ : Interview	NO :Interview	YES :Interview
TOTAL	1133					

Summarized Interview Information:

Age 0 – 1	Take bathe 2 (CTE) – 3 (RME) times/day (for 10 - 15 minutes)
Age 1 – 4	Shower 1 – 3 times/day (for 10 to 30 minutes) Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)
Age 5 – 14	Shower 2 – 3 times/day (for 10 to 30 minutes) Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Swim 1 – 3 times/week for 0.5 – 2 hour each time Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)
Age 15 – 60	Shower 2 – 4 times/day (for 10 to 30 minutes) Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Swim 3 – 5 times/week for 0.5 – 1 hour each time Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)
Age 60 and over	Shower 1 – 3 times/day (for 10 to 30 minutes) Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)

Village: Station/Mae Moh (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	5	Stay home with parents/relatives	NO (unable)	Bath	YES :Interview	NO :Unlikely
1-4	29	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	YES Interview	YES :Interview
5-14	116	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	YES :Interview	YES :Interview
15-59	476	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	YES :Interview	YES :Interview
60-80	94	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	YES :Interview	YES :Interview
TOTAL	721					

Summarized Interview Information:

- Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 10 - 15 minutes)
 Drink 0.25 – 0.75 L of water/day
- Age 1 – 4 Shower 2 – 3 times/day (for 10 to 30 minutes)
 Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day except 2 months in summer
 Drink 0.5 – 1.0 L of water/day
- Age 5 – 14 Eat fish 3 – 4 meals/week (about 100 – 200 grams each meal)
 Shower 2 – 3 times/day (for 10 to 30 minutes)
 Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day except 2 months in summer
 Swim 1 – 3 times/week for 0.5 – 2 hour each time
 Drink 1.5 – 2.5 L of water/day
- Age 15 – 60 Eat fish 3 – 4 meals/week (about 100 – 200 grams each meal)
 Shower 2 – 3 times/day (for 10 to 30 minutes)
 Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day except 2 months in summer
 Swim 4 – 5 times/week for 0.2 – 0.5 hour each time
 Drink 2 – 2.5 L of water/day (for 10 to 30 minutes)
- Age 60 and over Eat fish 3 – 4 meals/week (about 100 – 200 grams each meal)
 Shower 1 – 2 times/day
 Drink 1.5 – 2 L of water/day

Village: Ban Kom/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	1	Stay home with parents/relatives	NO (unable)	Bath	YES :Interview	NO :Unlikely
1-4	13	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	YES Interview	YES :Interview
5-14	77	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	YES :Interview	YES :Interview
15-59	369	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	YES :Interview	YES :Interview
60-80	76	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	YES :Interview	YES :Interview
TOTAL	536					

Summarized Interview Information:

- Age 0 – 1 Take bathe 1 (CTE) – 3 (RME) times/day (for 10 – 20 minutes)
 Drink 0.5 – 1.5 L of water/day
- Age 1 – 4 Shower 1 – 3 times/day (for 10 to 30 minutes)
 Go to farms 3 - 7 days/week, year-round, for 8 – 10 hours/day except for 2 months in summer
 Drink 1 – 1.5 L of water/day
- Age 5 – 14 Eat fish 3 – 6 meals/week (about 50 – 100 grams each meal)
 Shower 1 – 3 times/day (for 10 to 30 minutes)
 Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day except for 2 months in summer
 Swim 3 – 4 times/week for 0.5 – 1 hour each time
 Drink 1 – 2.5 L of water/day
- Age 15 – 60 Eat fish 3 – 6 meals/week (about 50 – 100 grams each meal)
 Shower 1 – 3 times/day (for 10 to 30 minutes)
 Go to farms 4 - 7 days/week, year-round, for 8 – 10 hours/day except for 2 months in summer
 Swim 2 – 5 times/week for 0.2 – 1 hour each time
 Drink 1.5 – 2 L of water/day
- Age 60 and over Eat fish 3 – 6 meals/week (about 50 – 100 grams each meal)
 Shower 1 – 2 times/day (for 10 to 30 minutes)
 Drink 1.5 – 2 L of water/day
 Eat fish 3 – 6 meals/week (about 50 – 100 grams each meal)

Village: Hua Sua/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	4	Stay home with parents/relatives	NO (unable)	Bath	YES :Interview	NO :Unlikely
1-4	27	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	YES Interview	YES :Interview
5-14	122	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	YES :Interview	YES :Interview
15-59	700	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	YES :Interview	YES :Interview
60-80	185	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	YES :Interview	YES :Interview
TOTAL	1038					

Summarized Interview Information:

- Age 0 – 1 Take bathe 1 (CTE) – 2 (RME) times/day (for 10 – 15 minutes)
 Drink 0.5 – 1.5 L of water/day
- Age 1 – 4 Shower 2 – 4 times/day (for 10 to 30 minutes)
 Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
 Hands and lower legs are exposed to water
 Drink 0.75 – 1.5 L of water/day
- Age 5 – 14 Eat fish 3 – 7 meals/week (about 100 – 150 grams each meal)
 Shower 2 – 4 times/day (for 10 to 30 minutes)
 Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
 Hands and lower legs are exposed to water
 Swim 2 – 3 times/week for 0.5 – 1 hour each time
 Drink 1 – 2.5 L of water/day
- Age 15 – 60 Eat fish 3 – 7 meals/week (about 100 – 150 grams each meal)
 Shower 2 – 3 times/day (for 10 to 30 minutes)
 Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
 Hands and lower legs are exposed to water
 Swim 3 – 5 times/week for 0.5 – 1 hour each time
 Drink 1.5 – 2.5 L of water/day
- Age 60 and over Eat fish 3 – 7 meals/week (about 100 – 150 grams each meal)
 Shower 1 – 2 times/day (for 10 to 30 minutes)
 Drink 1 – 2 L of water/day
 Eat fish 3 – 7 meals/week (about 100 – 150 grams each meal)

Village: Don Mun/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	3	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	22	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	78	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	368	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	107	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	578					

Summarized Interview Information: (no drinking from river water)

Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 10 – 20 minutes)

Age 1 – 4 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)

Age 5 – 14 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 2 – 4 times/week for 0.5 – 2 hour each time
Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)

Age 15 – 60 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 3 – 5 times/week for 0.5 – 1 hour each time
Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)

Age 60 and over Shower 1 – 3 times/day (for 10 to 30 minutes)
Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)

Village: Mae Lu/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	16	Stay home with parents/relatives	NO (unable)	Bath	YES :Interview	NO :Unlikely
1-4	38	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	YES Interview	YES :Interview
5-14	139	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	YES :Interview	YES :Interview
15-59	724	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	YES :Interview	YES :Interview
60-80	123	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	YES :Interview	YES :Interview
TOTAL	1040					

Summarized Interview Information:

- Age 0 – 1 Take bathe 1 (CTE) – 2 (RME) times/day (for 10 – 30 minutes)
 Drink 0.5 – 1 L of water/day
- Age 1 – 4 Shower 2 – 3 times/day (for 10 to 30 minutes)
 Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day except 3 months in summer
 Drink 0.5 – 1.0 L of water/day
- Age 5 – 14 Eat fish 2 – 4 meals/week (about 50 – 200 grams each meal)
 Shower 2 – 3 times/day (for 10 to 30 minutes)
 Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day except for 3 months in summer
 Swim 2 – 4 times/week for 0.3 – 1.5 hour each time
 Drink 1 – 2 L of water/day
- Age 15 – 60 Eat fish 2 – 4 meals/week (about 50 – 200 grams each meal)
 Shower 2 – 3 times/day (for 10 to 30 minutes)
 Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day except 3 months in summer
 Swim 3 – 6 times/week for 0.3 – 1 hour each time
 Drink 1.5 – 3 L of water/day
- Age 60 and over Eat fish 2 – 4 meals/week (about 50 – 200 grams each meal)
 Shower 1 – 3 times/day (for 10 to 30 minutes)
 Drink 1 – 2 L of water/day
 Eat fish 2 – 4 meals/week (about 50 – 200 grams each meal)

Village: Sop Rai/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	3	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	6	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	37	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	195	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	38	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	279					

Summarized Interview Information:

Age 0 – 1	Take bathe 2 (CTE) – 3 (RME) times/day (for 10 – 20 minutes)
Age 1 – 4	Shower 1 – 2 times/day (for 10 to 30 minutes) Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day except for 3 months in summer Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)
Age 5 – 14	Shower 1 – 3 times/day (for 10 to 30 minutes) Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day except for 3 months in summer Swim 2 – 3 times/week for 0.5 – 2 hour each time Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)
Age 15 – 60	Shower 2 – 3 times/day (for 10 to 30 minutes) Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day except for 3 months in summer Swim 3 – 4 times/week for 0.5 – 1 hour each time Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)
Age 60 and over	Shower 1 – 3 times/day (for 10 to 30 minutes) Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)

Village: Ban Mai1/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	5	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	25	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	93	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	484	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	88	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	695					

Summarized Interview Information:

Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 10 – 15 minutes)

Age 1 – 4 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Eat fish 2 – 3 meals/week (about 50 – 100 grams each meal)

Age 5 – 14 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 1 – 4 times/week for 0.5 – 2 hour each time
Eat fish 2 – 3 meals/week (about 50 – 100 grams each meal)

Age 15 – 60 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 2 – 6 times/week for 0.5 – 1 hour each time
Eat fish 2 – 3 meals/week (about 50 – 100 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
Eat fish 2 – 3 meals/week (about 50 – 100 grams each meal)

Village: Ban Mai8/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	6	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	21	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	85	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	427	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	101	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	640					

Summarized Interview Information:

Age 0 – 1	Take bathe 1 (CTE) – 3 (RME) times/day (for 10 – 20 minutes)
Age 1 – 4	Shower 1 – 3 times/day (for 10 to 30 minutes) Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Eat fish 3 – 7 meals/week (about 50 – 150 grams each meal)
Age 5 – 14	Shower 1 – 3 times/day (for 10 to 30 minutes) Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Swim 2 – 4 times/week for 0.5 – 2 hour each time Eat fish 3 – 7 meals/week (about 50 – 150 grams each meal)
Age 15 – 60	Shower 2 – 4 times/day (for 10 to 30 minutes) Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Swim 2 – 4 times/week for 0.5 – 1 hour each time Eat fish 3 – 7 meals/week (about 50 – 150 grams each meal)
Age 60 and over	Shower 1 – 2 times/day (for 10 to 30 minutes) Eat fish 3 – 7 meals/week (about 50 – 150 grams each meal)

Village: Pong Pa Pao/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	2	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	24	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	97	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	478	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	95	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	696					

Summarized Interview Information:

Age 0 – 1 Take bathe 1 (CTE) – 2 (RME) times/day (for 10 – 30 minutes)

Age 1 – 4 Shower 1 – 2 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Eat fish 2 – 3 meals/week (about 50 – 150 grams each meal)

Age 5 – 14 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 1 – 2 times/week for 0.5 – 2 hour each time
Eat fish 2 – 3 meals/week (about 50 – 150 grams each meal)

Age 15 – 60 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 3 – 5 times/week for 0.5 – 1 hour each time
Eat fish 2 – 3 meals/week (about 50 – 150 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
Eat fish 2 – 3 meals/week (about 50 – 150 grams each meal)

Village: Sop Po/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	6	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	17	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	38	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	199	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	46	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	306					

Summarized Interview Information:

Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 15 – 30 minutes)

Age 1 – 4 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Eat fish 3 – 5 meals/week (about 50 – 100 grams each meal)

Age 5 – 14 Shower 1 – 2 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 2 – 4 times/week for 0.5 – 2 hour each time
Eat fish 3 – 5 meals/week (about 50 – 100 grams each meal)

Age 15 – 60 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 5 – 6 times/week for 0.5 – 1 hour each time
Eat fish 3 – 5 meals/week (about 50 – 100 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
Eat fish 3 – 5 meals/week (about 50 – 100 grams each meal)

Village: Nam Thong/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	6	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	53	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	193	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	1059	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	245	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	1556					

Summarized Interview Information:

Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 15 – 30 minutes)

Age 1 – 4 Shower 1 – 2 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Eat fish 2 – 4 meals/week (about 150 – 200 grams each meal)

Age 5 – 14 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 2 – 3 times/week for 0.5 – 2 hour each time
Eat fish 2 – 4 meals/week (about 150 – 200 grams each meal)

Age 15 – 60 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 1 – 4 times/week for 0.5 – 1 hour each time
Eat fish 3 – 4 meals/week (about 150 – 200 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
Eat fish 2 – 4 meals/week (about 150 – 200 grams each meal)

Village: Ban Luk/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	5	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	35	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	147	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	791	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	204	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	1182					

Summarized Interview Information:

Age 0 – 1 Take bathe 1 (CTE) – 3 (RME) times/day (for 15 – 20 minutes)

Age 1 – 4 Shower 1 – 2 times/day (for 10 to 30 minutes)
Go to farms 4 - 6 days/week, year-round, for 8 – 10 hours/day except for 3 months in summer
Eat fish 2 – 3 meals/week (about 150 – 200 grams each meal)

Age 5 – 14 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day except for 3 months in summer
Swim 1 – 4 times/week for 0.5 – 2 hour each time
Eat fish 2 – 3 meals/week (about 150 – 200 grams each meal)

Age 15 – 60 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 4 - 6 days/week, year-round, for 8 – 10 hours/day except for 3 months in summer
Swim 2 – 3 times/week for 0.5 – 1 hour each time
Eat fish 2 – 3 meals/week (about 150 – 200 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
Eat fish 2 – 3 meals/week (about 150 – 200 grams each meal)

Village: Nong Thoi/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	9	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	37	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	145	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	598	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	110	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	899					

Summarized Interview Information:

Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 10 – 20 minutes)

Age 1 – 4 Shower 1 – 2 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Eat fish 2 – 5 meals/week (about 50 – 100 grams each meal)

Age 5 – 14 Shower 1 – 2 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 1 – 3 times/week for 0.5 – 2 hour each time
Eat fish 2 – 5 meals/week (about 50 – 100 grams each meal)

Age 15 – 60 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 2 – 4 times/week for 0.5 – 1 hour each time
Eat fish 2 – 5 meals/week (about 50 – 100 grams each meal)

Age 60 and over Shower 2 – 3 times/day (for 10 to 30 minutes)
Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)

Village: Ban Hom/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	4	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	31	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	133	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	693	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	195	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	1056					

Summarized Interview Information:

Age 0 – 1 Take bathe 1 (CTE) – 3 (RME) times/day (for 10 – 20 minutes)

Age 1 – 4 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day except for 2 months in summer
Eat fish 2 – 5 meals/week (about 50 – 100 grams each meal)

Age 5 – 14 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day except for 2 months in summer
Swim 1 – 3 times/week for 0.5 – 2 hour each time
Eat fish 2 – 5 meals/week (about 50 – 100 grams each meal)

Age 15 – 60 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day except for 2 months in summer
Swim 2 – 4 times/week for 0.5 – 1 hour each time
Eat fish 2 – 5 meals/week (about 50 – 100 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
Eat fish 2 – 5 meals/week (about 50 – 100 grams each meal)

Village: Ban Luk Tai/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	6	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	26	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	86	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	472	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	135	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	725					

Summarized Interview Information:

Age 0 – 1 Take bathe 1 (CTE) – 3 (RME) times/day (for 10 – 20 minutes)

Age 1 – 4 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Eat fish 3 – 7 meals/week (about 100 – 150 grams each meal)

Age 5 – 14 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 1 – 4 times/week for 0.5 – 2 hour each time
Eat fish 3 – 7 meals/week (about 100 – 150 grams each meal)

Age 15 – 60 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 2 – 5 times/week for 0.5 – 1 hour each time
Eat fish 3 – 7 meals/week (about 100 – 150 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
Eat fish 3 – 7 meals/week (about 100 – 150 grams each meal)

Village: Na Kwao/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	6	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	35	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	105	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	500	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	106	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	752					

Summarized Interview Information:

Age 0 – 1 Take bathe 1 (CTE) – 2 (RME) times/day (for 10 – 15 minutes)

Age 1 – 4 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Eat fish 2 – 5 meals/week (about 50 – 150 grams each meal)

Age 5 – 14 Shower 1 – 2 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 1 – 2 times/week for 0.5 – 2 hour each time
Eat fish 2 – 5 meals/week (about 50 – 150 grams each meal)

Age 15 – 60 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 2 – 6 times/week for 0.5 – 1 hour each time
Eat fish 2 – 5 meals/week (about 50 – 150 grams each meal)

Age 60 and over Shower 1 – 3 times/day (for 10 to 30 minutes)
Eat fish 2 – 5 meals/week (about 50 – 150 grams each meal)

Village: Ban Pao/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	5	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	51	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	139	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	662	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	170	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	1027					

Summarized Interview Information:

Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 15 – 30 minutes)

Age 1 – 4 Shower 2 – 4 times/day (for 10 to 30 minutes)
 Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day except 2 months in summer
 Eat fish 1 – 5 meals/week (about 100 – 200 grams each meal)

Age 5 – 14 Shower 1 – 2 times/day (for 10 to 30 minutes)
 Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day except 2 months in summer
 Swim 1 – 2 times/week for 0.5 – 2 hour each time
 Eat fish 1 – 5 meals/week (about 100 – 200 grams each meal)

Age 15 – 60 Shower 2 – 3 times/day (for 10 to 30 minutes)
 Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day except 2 months in summer
 Swim 2 – 5 times/week for 0.5 – 1 hour each time
 Eat fish 1 – 5 meals/week (about 100 – 200 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
 Eat fish 1 – 5 meals/week (about 100 – 200 grams each meal)

Village: Ban Na Khot/MaeTha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	10	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	33	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	169	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	1018	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	188	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	1206					

Summarized Interview Information:

Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 10 – 15 minutes)

Age 1 – 4 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Eat fish 1 – 4 meals/week (about 50 – 150 grams each meal)

Age 5 – 14 Shower 1 – 2 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 1 – 2 times/week for 0.5 – 2 hour each time
Eat fish 1 – 4 meals/week (about 50 – 150 grams each meal)

Age 15 – 60 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 1 – 5 times/week for 0.5 – 1 hour each time
Eat fish 1 – 4 meals/week (about 50 – 150 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
Eat fish 1 – 4 meals/week (about 50 – 150 grams each meal)

Village: Pa Tan Nua/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	8	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	24	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	121	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	674	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	183	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	1010					

Summarized Interview Information:

Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 10 – 20 minutes)

Age 1 – 4 Shower 2 – 4 times/day (for 10 to 30 minutes)
 Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
 Hands and lower legs are exposed to water
 Eat fish 2 – 7 meals/week (about 50 – 200 grams each meal)

Age 5 – 14 Shower 1 – 2 times/day (for 10 to 30 minutes)
 Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
 Hands and lower legs are exposed to water
 Swim 1 – 3 times/week for 0.5 – 2 hour each time
 Eat fish 2 – 7 meals/week (about 50 – 200 grams each meal)

Age 15 – 60 Shower 2 – 4 times/day (for 10 to 30 minutes)
 Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
 Hands and lower legs are exposed to water
 Swim 2 – 7 times/week for 0.5 – 1 hour each time
 Eat fish 2 – 7 meals/week (about 50 – 200 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
 Eat fish 2 – 7 meals/week (about 50 – 200 grams each meal)

Village: Pa Tan Tai/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	16	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	54	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	153	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	976	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	210	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	1449					

Summarized Interview Information

Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 10 – 15 minutes)

Age 1 – 4 Shower 2 – 4 times/day (for 10 to 30 minutes)
Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Eat fish 2 – 6 meals/week (about 100 – 200 grams each meal)

Age 5 – 14 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 2 – 4 times/week for 0.5 – 2 hour each time
Eat fish 2 – 6 meals/week (about 100 – 200 grams each meal)

Age 15 – 60 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 3 – 6 times/week for 0.5 – 1 hour each time
Eat fish 2 – 6 meals/week (about 100 – 200 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
Eat fish 2 – 6 meals/week (about 100 – 200 grams each meal)

Village: Sop Tha/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	4	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	11	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	50	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	272	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	57	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	394					

Summarized Interview Information:

Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 15 – 30 minutes)

Age 1 – 4 Shower 2 – 4 times/day (for 10 to 30 minutes)
 Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day except 3 months in summer
 Eat fish 3 – 4 meals/week (about 50 – 100 grams each meal)

Age 5 – 14 Shower 1 – 3 times/day (for 10 to 30 minutes)
 Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day except 3 months in summer
 Swim 1 – 4 times/week for 0.5 – 2 hour each time
 Eat fish 3 – 4 meals/week (about 50 – 100 grams each meal)

Age 15 – 60 Shower 1 – 3 times/day (for 10 to 30 minutes)
 Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day except 3 months in summer
 Swim 2 – 5 times/week for 0.5 – 1 hour each time
 Eat fish 3 – 4 meals/week (about 50 – 100 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
 Eat fish 3 – 4 meals/week (about 50 – 100 grams each meal)

Village: Ban To/Mae Tha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	22	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	63	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	243	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	1179	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	231	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	1738					

Summarized Interview Information:

Age 0 – 1 Take bathe 1 (CTE) – 3 (RME) times/day (for 15 – 30 minutes)

Age 1 – 4 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day except for 2 months in summer
Eat fish 2 – 4 meals/week (about 50 – 150 grams each meal)

Age 5 – 14 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day except for 2 months in summer
Swim 1 – 2 times/week for 0.5 – 2 hour each time
Eat fish 2 – 4 meals/week (about 50 – 150 grams each meal)

Age 15 – 60 Shower 1 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day except for 2 months in summer
Swim 2 – 5 times/week for 0.5 – 1 hour each time
Eat fish 2 – 4 meals/week (about 50 – 150 grams each meal)

Age 60 and over Shower 1 – 2 times/day (for 10 to 30 minutes)
Eat fish 2 – 4 meals/week (about 50 – 150 grams each meal)

Village: Ban Nong4/9/Mae Tha (Residential Scenario)				Possible Complete Pathways		
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1	16	Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4	74	Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14	320	Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59	1414	Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80	224	Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL	2048					

Summarized Interview Information:

Age 0 – 1 Take bathe 2 (CTE) – 3 (RME) times/day (for 15 – 20 minutes)

Age 1 – 4 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Eat fish 2 – 5 meals/week (about 50 – 100 grams each meal)

Age 5 – 14 Shower 2 – 3 times/day (for 10 to 30 minutes)
Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 1 – 2 times/week for 0.5 – 2 hour each time
Eat fish 2 – 5 meals/week (about 50 – 100 grams each meal)

Age 15 – 60 Shower 2 – 4 times/day (for 10 to 30 minutes)
Go to farms 5 - 7 days/week, year-round, for 8 – 10 hours/day
Hands and lower legs are exposed to water
Swim 2 – 7 times/week for 0.5 – 1 hour each time
Eat fish 2 – 5 meals/week (about 50 – 100 grams each meal)

Age 60 and over Shower 1 – 3 times/day (for 10 to 30 minutes)
Eat fish 2 – 5 meals/week (about 50 – 100 grams each meal)

Village: Wang Phrao/Ko Kha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1		Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4		Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14		Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59		Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80		Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL						

Summarized Interview Information:

Age 0 – 1	Take bathe 1 (CTE) – 2 (RME) times/day (for 10 – 20 minutes)
Age 1 – 4	Shower 2 – 4 times/day (for 10 to 30 minutes) Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Eat fish 3 – 4 meals/week (about 50 – 200 grams each meal)
Age 5 – 14	Shower 2 – 3 times/day (for 10 to 30 minutes) Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Swim 1 – 2 times/week for 0.5 – 2 hour each time Eat fish 3 – 4 meals/week (about 50 – 200 grams each meal)
Age 15 – 60	Shower 2 – 3 times/day (for 10 to 30 minutes) Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Swim 2 – 5 times/week for 0.5 – 1 hour each time Eat fish 3 – 4 meals/week (about 50 – 200 grams each meal)
Age 60 and over	Shower 1 – 3 times/day (for 10 to 30 minutes) Eat fish 3 – 4 meals/week (about 50 – 200 grams each meal)

Village: Sop Chang/Ko Kha (Residential Scenario)			Possible Complete Pathways			
Ages of Receptors	#	Description	DC @ Farming/ Bathe	DC @ Swimming	Ingestion @ drinking water	Ingestion @ eating fish
0-1		Stay home with parents/relatives	NO (unable)	Bath	NO :Interview	NO :Unlikely
1-4		Stay home/go with parents to farm	All go to farm with parents	Unable to swim	NO :Interview	YES :Interview
5-14		Go to school during weekdays stay home during weekend	During Weekends :Interview	During weekends and holiday Interview	NO :Interview	YES :Interview
15-59		Stay home/go to farm, fishing, swimming, eat fish, drink river water	Small number do not go to farms	Swim occasionally Interview	NO :Interview	YES :Interview
60-80		Stay home and take care of children	Stay home :Interview	Unlikely to swim/ Interview	NO :Interview	YES :Interview
TOTAL						

Summarized Interview Information:

Age 0 – 1	Take bathe 1 (CTE) – 2 (RME) times/day (for 10 – 20 minutes)
Age 1 – 4	Shower 1 – 3 times/day (for 10 to 30 minutes) Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)
Age 5 – 14	Shower 2 – 3 times/day (for 10 to 30 minutes) Go to farms 1 - 2 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Swim 1 – 2 times/week for 0.5 – 2 hour each time Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)
Age 15 – 60	Shower 2 – 3 times/day (for 10 to 30 minutes) Go to farms 5 - 6 days/week, year-round, for 8 – 10 hours/day Hands and lower legs are exposed to water Swim 2 – 4 times/week for 0.5 – 1 hour each time Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)
Age 60 and over	Shower 1 – 3 times/day (for 10 to 30 minutes) Eat fish 2 – 4 meals/week (about 50 – 100 grams each meal)



MAE-MOH POWER PLANT

Dust (PM 10) Report: Division **กปถม-พ2** Department

From **วท.4 วิศวกรรม-พ2**
 Date Report **4/7/45**
 Date Received **4/7/45**
 CC **ศูนย์สิ่งแวดล้อมอุตสาหกรรม**

Attention to **วท.กม-พ2 ฝ่าย วท. 4**
 Inspection Area **Silo 4-13**
 Inspected By **นายสมพงษ์ อธิสุขาวรณ์**

D-M-Y	Area	Start time	Off time	Elapsed time	mg/m ³		Result		Other
					Max conc.	TLV-TWA	Satisfied	Unsatisfied	
3/6/45	Silo 5	9.30	15.28	5.58	-	0.170	/	/	1. Objective เพื่อความปลอดภัยในการทำงาน 2. Measurement By : ☒ MIE Mod Miniram M/D POM 3D ☒ Personal DATA RAM models pDR-1200 3. Reference : มาตรฐานประกาศกรมการรัวโรลาหกิจสัมพันธ์ โดยกำหนดให้ฝุ่นแ่งที่มี ส่วนผสมของ Silica Quartz มากกว่า 5% มีค่า TLV-TWA ไม่เกิน 0.243 mg/m ³ 4. Summarize : ผลการตรวจวัดจำนวน 9 จุด มี 5 จุดตรวจวัดที่มีฝุ่นสูงกระจายเกินค่ามาตรฐาน 5. Advise : อันตรายของฝุ่น นอกจากจะก่อให้เกิดการเปลี่ยนแปลงของกรีนเงินปอดแล้ว ยังทำให้สมรรถภาพการทำงานลดลงเมื่อมลง การลดปริมาณฝุ่นในบรรยากาศการทำงานให้ได้ผลดีที่สุด คือ การป้องกัน และควบคุมไม่ให้เกิดฝุ่นที่กระจายจากแหล่งกำเนิด และจัดหาอุปกรณ์ป้องกันอันตรายส่วนบุคคลด้านป้องกันระบบหายใจ ที่มีประสิทธิภาพสูงเหมาะสมแก่การใช้งานให้กับผู้ปฏิบัติงาน 6. Remarks : Silo 4 และ 11 Shut down <u> </u> <u> </u> (Industrial Hygienist)
6/6/45	Silo 6	9.30	15.48	6.18	-	0.560	/	/	
7/6/45	Silo 7	9.49	15.46	5.58	406.116	4.728	/	/	
4/6/45	Silo 8	9.45	15.43	5.58	-	0.270	/	/	
4/6/45	Silo 9	10.14	16.11	5.57	42.299	0.107	/	/	
5/6/45	Silo 10	9.30	15.20	5.50	-	0.300	/	/	
5/6/45	Silo 12	9.51	15.34	5.43	11.268	0.084	/	/	
6/6/45	Silo 13	9.23	15.55	6.32	97.276	0.112	/	/	
7/6/45	ZT 91	9.30	15.16	5.46	-	0.450	/	/	

SF-61-ASS-01-01

การไฟฟ้าฝ่ายผลิตแห่งประเทศไทย

บันทึก

จาก วท.4 วทกม-ฟ2

เรื่อง ผลการตรวจวัดฝุ่น

วันที่ 11 กุมภาพันธ์ 2545

เรียน

วทกม-ฟ2 ผ่าน วท.8

(นายสมเกียรติ สอนวิชาประไฟ)

งานสุขศาสตร์อุตสาหกรรม วิศวกรรมควบคุมความปลอดภัยโรงไฟฟ้าแม่เมาะ ได้ทำการตรวจ
วัดฝุ่น(Respirable dust)บริเวณ Silo 4-13 และ ZT 91 ดังรายละเอียดต่อไปนี้

วัน/เดือน/ปี	สถานที่	ช่วงเวลาตรวจวัด (น.)	ระยะเวลา (ชั่วโมง)	วัดค่าได้ mg/m^3		ผลการตรวจวัด	
				ค่าสูงสุด	ค่าเฉลี่ย 8 ชม.	ผ่าน	ไม่ผ่าน
08/01/45	Silo 4	09.23-15.25	6.02	249.015	1.335	/	/
09/01/45	Silo 5	19.21-16.01	6.40	1.431	0.143	/	/
15/01/45	Silo 6	09.15-16.04	6.49	10.320	0.161	/	/
16/01/45	Silo 7	19.32-16.05	6.33	5.928	0.170	/	/
17/01/45	Silo 8	09.34-14.31	4.57	125.854	0.483	/	/
23/01/45	Silo 10	09.25-14.05	4.40	-	0.42	/	/
23/01/45	Silo 11	09.24-15.32	6.08	8.953	0.174	/	/
24/01/45	Silo 12	09.34-15.28	5.54	-	0.630	/	/
25/01/45	Silo 13	09.30-15.30	6.00	3.552	0.137	/	/
25/01/45	ZT 91	09.35-15.09	5.34	-	0.33	/	/

หมายเหตุ : - จุดที่ติดตั้งเครื่องมือตรวจวัดสถานที่ Silo คือบริเวณกระเบียงนอกห้อง Operator
- ช่วงเวลาที่ทำการตรวจวัด Silo 9 Shut Down

เครื่องมือที่ใช้ในการตรวจวัด : - MIE Mod Miniram M/D POM 3D
- personal DATA RAM models pDR-1200

ค่ามาตรฐาน : ใช้มาตรฐานประกาศกรมการรัฐวิสาหกิจสัมพันธ์ เรื่องความปลอดภัยในการทำงานเกี่ยวกับภาวะแวดล้อม(สารเคมี) โดยกำหนดให้ ฝุ่นที่มีส่วนผสมของ % Silica Quartz มากกว่า 5 % มีค่าเฉลี่ยระยะเวลาการทำงานปกติ 8 ชั่วโมง/วัน (TLV-TWA) ไม่เกิน $0.243 mg/m^3$



2003											
	A	B	C	D	E	F	G	H	I	J	K
1			Unit								
2	Date	Total Ton	4	5	7	8	9	10	11	12	13
3	2-Jan-03	3030.76		158.95	388.07	333.38			601.63	709.24	839.49
4	3-Jan-03	3241.7		385.96	409.82	508.11			659.3	553.17	725.34
5	4-Jan-03	3179.18		233.42	231.86	448.65		584.34	562.82	534.59	583.5
6	5-Jan-03	2806.17		105.16	56.66	401.08	202.11	425.35	554.71	416.88	644.22
7	6-Jan-03	2428.19		150.41	171.55	304.59	298.32	331.81	427.33	445.47	298.71
8	7-Jan-03	3202.54		331.9	371.19	502.58	505.6	425.57	283.77	319.85	462.08
9	8-Jan-03	3190.09		284.17	193.64	471.4	351.93	324.57	540.66	428.39	595.33
10	9-Jan-03	2980.74		168.11	20.66	416.84	534.01	385.78	569.64	410.55	475.15
11	10-Jan-03	3358.42		297.64	302.91	682.55	487.38	412.64	316.9	428.71	429.69
12	11-Jan-03	2722		192.51	263.12	495.33	428.7	326.95	108.02	549.86	357.51
13	12-Jan-03	2146.88		143.17	189.95	412.12	314.7	365.64		370.28	351.02
14	13-Jan-03	2529.77		125.51	144.44	487.57	368.74	550.97		448.19	404.35
15	14-Jan-03	2266.77		120.85	142.49	372.19	519.84	129.48		542.1	439.82
16	15-Jan-03	2255.77			127.31	170.88	284.18	512.06	327.34	586.7	247.3
17	16-Jan-03	3051.14				673.75	274.75	468.96	542.24	497.45	593.99
18	17-Jan-03	3260.19		20.53	213.46	515.1		516.52	621.88	699.18	673.52
19	18-Jan-03	2045.24		120.75	160.11	358.96		428.91	187.71	362.61	426.19
20	19-Jan-03	3736.8		377.46	286.86	679.77	15.85	689.71	573.84	630.42	482.89
21	20-Jan-03	3116.78		197.64	335.18	484.54		550.93	497.95	507.82	542.72
22	21-Jan-03	3571.17		228.64	344.85	469.91	96.69	655.88	552.44	613.69	609.07

re@yahoo.com

23	22-Jan-03	3531.26		63.59	265.04	353.26	562.46	565.64	599.38	672.3	449.59
24	23-Jan-03	3972.06		149.03	268.67	548.12	619.41	707.96	484.19	652.33	542.35
25	24-Jan-03	4196.48		271.07	314.31	651.54	470.48	560.98	590.42	687.79	649.89
26	25-Jan-03	3817.65		133.05	262.56	825.66	434.9	660.38	474.22	435.51	591.37
27	26-Jan-03	3437.71		295.49	259.63	510.54	432.69	592.88	322.07	432.91	591.5
28	27-Jan-03	4178.99		209.46	411.86	517.41	478.44	787.96	495.96	605.2	672.7
29	28-Jan-03	5122.23		409.13	190.24	679.46	941.04	777.92	666.26	711.44	746.74
30	29-Jan-03	4158.79		169.71	189.4	582.05	609.24	657.47	752.02	659.69	539.21
31	30-Jan-03	4197.76		132.88	156.19	584.72	728.25	600.18	671	605.29	719.25
32	31-Jan-03	3774.98		242.08	223.84	607.4	447.72	571.07	562.73	504.97	615.17
33	1-Feb-03	4401.64		222.88	371.9	576.36	482.4	846.35	505.32	715.36	681.07
34	2-Feb-03	4602.87		134.08	166.3	751.51	752.55	738.22	643.1	800.77	616.34
35	3-Feb-03	4965.59		322.09	305.89	738.34	618.55	803.93	676.01	749.97	750.81
36	4-Feb-03	4075.82		145.87	241.63	633.47	539.16	473.59	580.58	777.8	683.72
37	5-Feb-03	5454.7		61.2	360.08	963.44	637.95	956.48	800.04	402.97	1272.54
38	6-Feb-03	4777.98		382.43	707.41	205.23	554.03	723.68	708.09	773.48	723.63
39	7-Feb-03	4243.11		532.71	325.82	492.75	549.69	691.78	539.61	482.48	628.27
40	8-Feb-03	5993.3		937.5	781.17	902.4	768.7	764.38	837.99	713.29	287.87
41	9-Feb-03	4282.72		373.95	401.18	685.58	629.31	788.54	793.9	610.26	
42	10-Feb-03	4019.54		280.25	586.98	513.87	664.6	660.71	596.8	716.33	
43	11-Feb-03	4040.89		476.8	448.08	620.2	603.16	748.81	588.82	555.02	
44	12-Feb-03	3879.9		351.29	342.75	516.29	559	565.94	492.97	501.87	549.79
45	13-Feb-03	3318.21		178.15	194.74	371.55	469.83	249.39	578.91	617.37	658.27
46	14-Feb-03	3135.53		227.11	273.61	311.86	396.32	478.96	383.64	493.52	570.51
47	15-Feb-03	2943.23		89.62	147.26	264.64	557.35	397.46	402.62	547.24	537.04
48	16-Feb-03	3260.57		376.95	382.52	310.26	512.83	461.91	539.19	646.72	30.19
49	17-Feb-03	3566.18		245.39	231.08	377.88	511.74	539.47	675.78	614.92	369.92
50	18-Feb-03	4540.8		463.61	328.94	610.05	477.78	652.39	580.07	808.76	619.2
51	19-Feb-03	4493.67		257.76	235.98	636.98	553.21	638.76	830.81	600.04	740.13
52	20-Feb-03	3843.76		194.95	313.92	103.4	655.9	708.43	569.75	565.4	732.01
53	21-Feb-03	3892.36		345.47	485.1		620.28	376.07	681.54	627.17	756.73
54	22-Feb-03	5090.08		622	376.14	411.77	767.44	764.64	679.34	672.1	796.65
55	23-Feb-03	4728.14		485.09	656.7	516.88	645.35	618.97	426.11	673.52	705.52
56	24-Feb-03	4431.99		426.65	339.68	117.96	769.11	653.7	588.33	735.05	801.51
57	25-Feb-03	4550.83		319.35	327.55	451.03	606.1	856.61	715.51	596.79	677.89
58	26-Feb-03	4684.49		176.38	364.74	536.6	730.87	841.41	851.85	553.86	628.78
59	27-Feb-03	3692.77		212.28	120.57	432.56	542.2	545.98	587.67	653.89	597.62



RISK*ASSISTANT for Windows Report

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procedures used by **RISK*ASSISTANT** to calculate exposures have been reviewed by the Office of Health and Environmental Assessment of the U.S. EPA. Default parameters for calculating exposures have been extracted from these U.S.EPA documents:

U.S.EPA, Office of Solid Waste and Emergency Response, Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors. Directive 9285.6-03; Interim Final. March 25, 1991.

J.Konz, K.Lisi, and E. Friebele, *Exposure Factors Handbook* U.S.EPA, Office of Health and Environmental Assessment, EPA/600/8-89/043; March 1989.

Aggregation Method Used in Analysis

The following table lists the technique used to combine data from multiple samples (i.e., the aggregation Method) for each environmental medium included in the analysis. For each class of data, a qualifier that might apply to the sample set (non-detects, estimated values, controls not within limits, or concentration estimated at a dilution factor), the approach used to assign a concentration to the qualified data values is presented.

Contaminated Medium	Aggregation Method	Treatment of Qualified Samples			
		NonDetect (U)	Estimated (J)	Cts not within limits (R,B,E,M,N,W,*)	Dilution Factor (D)

Four options are available for dealing with qualified sample data (i.e., concentration values for which a proxy value has been entered, accompanied by one of the four classes of data qualifiers recognized by **RISK*ASSISTANT**). A separate decision can be made for each class of qualified data. The user may either use all proxy values as entered, use one-half of the entered proxy value, exclude (drop) the qualified data, or set the concentration for the qualified data to zero.

Chemical Concentrations in Contaminated Media

The concentration values presented in this table are expressed using the S.I. (Système International, also called metric) units most commonly employed in risk assessment. They may differ from the units used in data entry.

AS#	Chemical Name									
	GW	SW	Air	Soil	Sed	Veget	Fruit	Fish	Dairy	Meat
	<u>ug/l</u>	<u>ug/l</u>	<u>ug/cu m</u>	<u>mg/kg</u>	<u>mg/kg</u>	<u>ug/kg</u>	<u>ug/kg</u>	<u>ug/kg</u>	<u>ug/kg</u>	<u>ug/kg</u>
10-38-2	ARSENIC AND COMPOUNDS									
	0.0287									

OTE: scientific notation is used for numbers less than 0.000001 and greater than 1000000.
For example: 0.00000021 = 2.1e-7 = 2.1 / 1000000 and 21000000 = 2.1e7 = 2.1 * 10000000.
GW = Groundwater, SW = Surface Water, Sed = Sediment, Veget = Vegetable.

The listed concentration in each medium for a chemical reflects the selection of sample values employed in aggregation, the aggregation method selected, and the approach used for dealing with qualified data. Where concentration data were entered directly, the assessor should be prepared to explain the values that were chosen.

Exposure Scenarios

In **RISK*ASSISTANT**, every exposure scenario is associated with a single contaminated medium. While some scenarios potentially apply to more than one medium, any individual assessment must assign a scenario to only one contaminated medium.

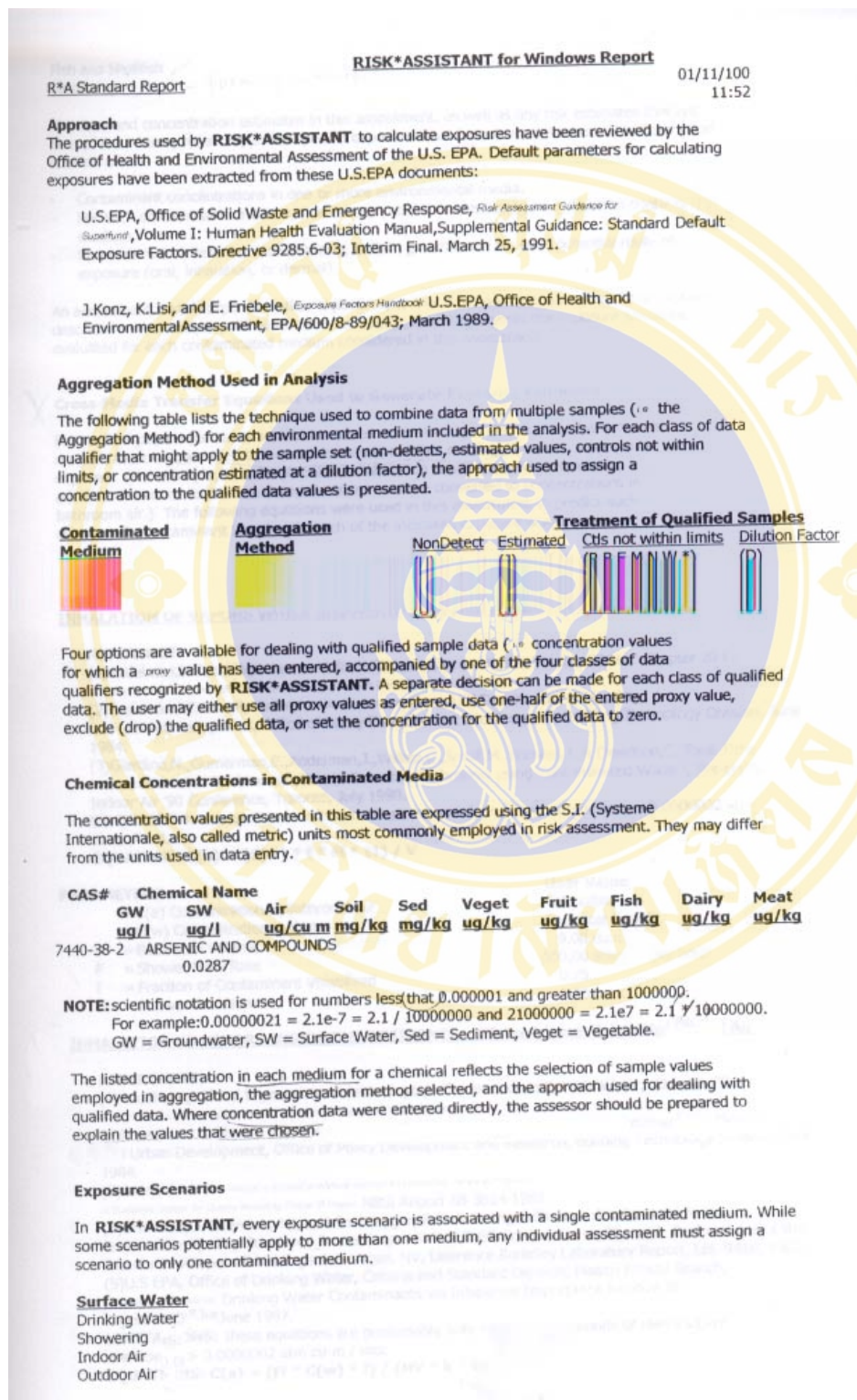
Surface Water

Drinking Water

Showering

Indoor Air

Outdoor Air



RISK*ASSISTANT for Windows Report

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Approach
The procedures used by **RISK*ASSISTANT** to calculate exposures have been reviewed by the Office of Health and Environmental Assessment of the U.S. EPA. Default parameters for calculating exposures have been extracted from these U.S.EPA documents:

U.S.EPA, Office of Solid Waste and Emergency Response, *Risk Assessment Guidance for Superfund*, Volume I: Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors. Directive 9285.6-03; Interim Final. March 25, 1991.

J.Konz, K.Lisi, and E. Friebele, *Exposure Factors Handbook* U.S.EPA, Office of Health and Environmental Assessment, EPA/600/8-89/043; March 1989.

Aggregation Method Used in Analysis

The following table lists the technique used to combine data from multiple samples (i.e. the Aggregation Method) for each environmental medium included in the analysis. For each class of data qualifier that might apply to the sample set (non-detects, estimated values, controls not within limits, or concentration estimated at a dilution factor), the approach used to assign a concentration to the qualified data values is presented.

Contaminated Medium	Aggregation Method	Treatment of Qualified Samples		
		NonDetect (U)	Estimated (J)	Controls not within limits (R,B,E,M,N,W,*) Dilution Factor (D)

Four options are available for dealing with qualified sample data (i.e. concentration values for which a proxy value has been entered, accompanied by one of the four classes of data qualifiers recognized by **RISK*ASSISTANT**. A separate decision can be made for each class of qualified data. The user may either use all proxy values as entered, use one-half of the entered proxy value, exclude (drop) the qualified data, or set the concentration for the qualified data to zero.

Chemical Concentrations in Contaminated Media

The concentration values presented in this table are expressed using the S.I. (Système Internationale, also called metric) units most commonly employed in risk assessment. They may differ from the units used in data entry.

CAS#	Chemical Name	GW	SW	Air	Soil	Sed	Veget	Fruit	Fish	Dairy	Meat
		ug/l	ug/l	ug/cu m	mg/kg	mg/kg	ug/kg	ug/kg	ug/kg	ug/kg	ug/kg
7440-38-2	ARSENIC AND COMPOUNDS										
			0.0287								

NOTE: scientific notation is used for numbers less than 0.000001 and greater than 1000000.
For example: 0.00000021 = 2.1e-7 = 2.1 / 10000000 and 21000000 = 2.1e7 = 2.1 * 10000000.
GW = Groundwater, SW = Surface Water, Sed = Sediment, Veget = Vegetable.

The listed concentration in each medium for a chemical reflects the selection of sample values employed in aggregation, the aggregation method selected, and the approach used for dealing with qualified data. Where concentration data were entered directly, the assessor should be prepared to explain the values that were chosen.

Exposure Scenarios

In **RISK*ASSISTANT**, every exposure scenario is associated with a single contaminated medium. While some scenarios potentially apply to more than one medium, any individual assessment must assign a scenario to only one contaminated medium.

Surface Water
Drinking Water
Showering
Indoor Air
Outdoor Air

Fish and Shellfish Swimming

The dose and concentration estimates in this assessment, as well as any risk estimates that are derived from them, refer only to the specific exposures that have been described. This description consists of:

- Contaminant concentrations in one or more environmental media.
- For each contaminated medium, one or more scenarios describing how a person contacts that medium.
- Parameters that describe each scenario, both in general, and for each potential route of exposure (oral, inhalation, or dermal).

An assessment that incorporates other exposures, or that does not incorporate all of the exposures described in this analysis, will yield different results. This list presents the exposure scenarios evaluated for each contaminated medium considered in this assessment.

Cross-Media Transfer Equations Used to Generate Exposure Estimates

For some exposure scenarios a contaminant concentration specified in one environmental medium must be converted to a concentration in another medium, to which a person is exposed. (For example, in order to evaluate inhalation exposures while showering, contaminant concentrations in domestic water must be converted to concentrations in bathroom air.) The following equations were used in this assessment to predict such cross-media contaminant transfers in each of the indicated exposure scenarios.

INHALATION OF VAPORS WHILE SHOWERING - Water (shower) to shower stall air

REFERENCE:

- (1) Andelman, J. 'Total Exposure to Volatile Organic Compounds in Potable Water,' Chapter 20 in *Significance and Treatment of Volatile Organic Compounds in Water Supplies*
- (2) Brown and Caldwell, *Residential Water Concentration Projects* U.S Department of Housing and Urban Development, Office of Policy Development and Research, Building Technology Division, June 1984.
- (3) Giardino, N., Gumerman, E., Andelman, J., Wilkes, C., Small, M., Borrazo, J., & Davidson, C., 'Real-Time Measurements of Trichloroethylene in Domestic Bathrooms using Contaminated Water.', Pre-print, Indoor Air '90 Conference, Toronto, July 1990.

LIMITATION: the equation is valid for compounds of Henry's Law coefficients > 0.0000002 atm cu m / mol.

$$\text{EQUATION: } C(a) = (C(w) * f * FI * t1) / V$$

PARAMETERS

C(a) Concentration in Bathroom Air
C(w) Concentration in Water
V = Bathroom Volume
F = Shower Flow Rate
f = Fraction of Contaminant Volatilized
t1 = Shower Duration

User Value

Calculated
Chemical Specific
9.00 cu.m
600.00 liters per hour
0.75
0.20 hours

INHALATION OF VAPORS INSIDE THE RESIDENCE - Water (domestic) to Household Air

REFERENCES:

- (1) Andelman, J. 'Total Exposure to Volatile Organic Compounds in Potable Water,' Chapter 20 in *Significance and Treatment of Volatile Organic Compounds in Water Supplies*
- (2) Brown and Caldwell, *Residential Water Concentration Projects* U.S Department of Housing and Urban Development, Office of Policy Development and Research, Building Technology Division, June 1984.
- (3) Axley, J. *Progress toward a general analytical method for predicting indoor air Pollution in Buildings: Indoor Air Quality Modeling Phase III Report* NBSI Report 88 3814-1988.
- (4) Grimsrud, D. Sherman, M., and Sondregger, R. 'Calculating Infiltration: Implications for a Construction Quality Standard.' Proceedings ASHRAE/DEO Conference on Thermal Performance of the Exterior Envelopes of Buildings. Las Vegas, NV, Lawrence Berkeley Laboratory Report, LBL-9416, 1982.
- (5) U.S EPA, Office of Drinking Water, Criteria and Standard Division, Health Effects Branch, *Exposure to Volatilized Drinking Water Contaminants via Inhalation Importance Relative to Ingestion*. Draft, June 1987.

LIMITATIONS: these equations are presumably only valid for compounds of Henry's Law coefficients > 0.0000002 atm cu m / mol.

$$\text{EQUATIONS: } C(a) = (FI * C(w) * f) / (HV * k * ER)$$

PARAMETERS

C(a) Concentration in inhabited air spaces of house.	Calculated
C(w) Concentration in water	Chemical Specific
FI = Water Flow Through the House	723.00 liters per day
f = Fraction of Contaminant Volatilized	0.50
HV = House Volume	177.70 cu.m per house
k = Mixing Coefficient	0.15
ER = Air Exchange Rate	13.70 hour(s) per day

INHALATION OF VAPORS OUTSIDE THE RESIDENCE - Water (irrigation) to Local Air

REFERENCES: Wilson, R.'Simple Area Source Algorithm for Risk Assessment Screening.' Memorandum to P. Cirone, U.S.EPA Health and Environmental Assessment Section, March 7, 1990.

LIMITATIONS: these equations are valid for compounds with Henry's Law > 0.0000002 atm cu m / mol

EQUATIONS: $Q(a) = (FI * f * C(w)) / (X ** 2)$ $C(a) = ((2/pi)**0.5 * (X ** (1 - b)) / (a * (1 - b))) * (Q(a) / u)$

PARAMETERS

C(a) Concentration in Air	Calculated
C(w) Concentration in Water	Chemical Specific
Q(a) Emission Source Strength	Calculated
f = Fraction Of contaminant volatilized:	0.50
FI = Flow of Irrigation water:	600.00 liters per hour
X = Width of Square Irrigated Area:	10.00 m
a = Stability Constant:	0.15
b = Stability Constant:	0.75
u = Near Surface Wind Speed:	2.00 m per sec

CONSUMPTION OF RECREATIONALLY CAUGHT FISH & SHELLFISH-Water to Edible Tissue

REFERENCES:

(1)U.S. EPA, Office of Toxic Substances, *Methods of Assessing exposure to Chemical Substances* Vol 8:Methods for Assessing Environmental Pathways of Food Contamination. EPA 560/5-85-008, September 1986.

(2)U.S.EPA, Office of Toxic Substances, *Estimating Toxicity of Industrial Chemicals to Aquatic Organisms Using Structure Activity Relationships* EPA/560/6-88-001, 1988.

LIMITATIONS: If log Kow > 8.0, more than 28 days will be required for equilibrium conditions to be reached.

EQUATIONS: $(1)C(f) = BCF * (Fat / 3) * C(w)$; $(2)\log(BCF) = (0.79 * \log(Kow)) - 0.40$

PARAMETERS

C(t) Concentration in edible tissue	Calculated
C(w) Concentration in (water)	Chemical Specific
Fat = Fat Content of Edible Portion of Fish	3.00%
BCF = Bioconcentration Factor for Tissue Fat	Chemical Specific
Kow = Octanol-water partition coefficient of the compound	Chemical Specific

Concentrations in Media after Transfers

For some exposure scenarios a contaminant concentration specified in one environmental medium must be converted to a concentration in another medium, to which a person is exposed. For example, in order to evaluate inhalation exposures while showering, contaminant concentrations in domestic water must be converted to concentrations in bathroom air. The values presented in this table are concentrations of contaminants in exposure media that have been predicted for specific exposure scenarios from concentrations that were specified in other media.

Chemical Name

Contaminated Media / Scenario	Calculated Concentrations										
	GW ug/l	SW ug/l	Air ug/cu m	mg/kg	Soil mg/kg	Sed ug/kg	Veget ug/kg	Fruit ug/kg	Fish ug/kg	Dairy ug/kg	Meat ug/kg

7440-38-2 **ARSENIC AND COMPOUNDS**

Surface Water

Showering	(2)											5.7e-012
Indoor Air			(2)									

Outdoor Air (2) 1.263
 Fish and Shellfish 7.7e-011
 Swimming

NOTE: scientific notation is used for numbers less than 0.000001 and greater than 1000000.

For example: $0.00000021 = 2.1 \times 10^{-7} = 2.1 / 10000000$ and $21000000 = 2.1 \times 10^7 = 2.1 \times 10000000$.
 GW = Groundwater, SW = Surface Water, Sed = Sediment, Veget = Vegetable.

Derm.Ab. = Dermal Absorption Rate, (1) Indicates Outside Model Bounds, (2) Indicates Missing Data

The accuracy of these predicted concentrations depends upon the extent to which the cross-media transfer equations used to derive them are appropriate to the specific exposure under consideration, and upon the use of appropriate parameter values in those equations. The values reported for dermal absorption are not concentrations, but rather represent rates of contaminant absorption, stated as milligrams of contaminant absorbed per square centimeter of exposed skin for each exposure event.

Exposure Parameters Used to Generate Exposure Estimates

The dose (or exposure concentration) values presented in this assessment reflect not only the concentrations of contaminants in various environmental media and the exposure pathways selected for analysis, but also the specific numerical parameters applied to each exposure scenario. The following tables summarize the exposure parameters used in this assessment.

Population: Avg American (RME)

General Population Parameters

Body Weight: 70.00 kg
 Lifetime: 70.00 years
 Exposure Period: 30 years

Scenario Specific Parameters

Scenario	Event Frequency	General Parameters	Event Duration
Drinking Water	350 events per year		
Showering	350 events per year	0.2 hours per event	
Indoor Air	350 events per year	21 hours per event	
Outdoor Air	350 events per year	3 hours per event	
Fish and Shellfish	350 events per year		
Swimming	7 events per year	2.7 hours per event	

Scenario	Amount Ingested	ORAL Fraction Contamin.	INHALATION Breathing Rate	DERMAL Exposed Skin Area
Drinking Water	2 liters per event	100 %	0.6 cu.m per hour	23000 sq.cm
Showering			0.71 cu.m per hour	
Indoor Air			1.67 cu.m per hour	
Outdoor Air				
Fish and Shellfish	0.054 kg per event	100 %		
Swimming	50 ml per hour	100 %		23000 sq.cm

Average Daily Dose or Exposure Concentration

When an exposure assessment will be used as part of a quantitative risk assessment, a numerical estimate of exposure must be calculated. The value employed for this estimate varies, according to the route of exposure.

When evaluating the risk of chronic non-cancer health effects from oral or dermal exposures, EPA employs the Average Daily Dose (ADD) received during the period of exposure. These are compared to Reference Doses (RfDs). When evaluating such effects from inhalation exposure, EPA employs contaminant concentrations, which are compared to Reference Concentrations (RfCs) for continuous exposure.

ADD = Average Daily Dose (during exposure period).
 Units are milligrams of contaminant per kilogram of body weight per day.

Inh.Conc = Concentration of contaminant in inhaled air.

Units are milligrams of contaminant per cubic meter of air.

Chemical Medium Scenario	Oral ADD mg/kg/d	Inhalation Concentration mg/cu m	Dermal ADD mg/kg/d
7440-38-2 ARSENIC AND COMPOUNDS			
Surface Water			
Drinking Water	7.9e-007		
Showering		Missing Data	1.8e-009
Indoor Air		Missing Data	
Outdoor Air		Missing Data	
Fish and Shellfish	9.3e-007		
Swimming	1.1e-009		4.9e-010
TOTALS	0.000002		2.3e-009

NOTE: scientific notation is used for numbers less than 0.000001 and greater than 1000000.
For example: $0.00000021 = 2.1 \times 10^{-7} = 2.1 / 10000000$ and $21000000 = 2.1 \times 10^7 = 2.1 * 10000000$.
ADD/LADD values are meaningful up to the second significant digit.

Lifetime Average Daily Dose or Adjusted Exposure Concentration

When evaluating carcinogenic risks from exposures that last less than a lifetime, the ADD or exposure concentration is adjusted to a dose or concentration that would yield an equivalent exposure if exposure continued for the entire lifetime.

For oral or dermal exposures, this yields the Lifetime Average Daily Dose (LADD):

$$LADD = ADD * (\text{exposure period in years} / \text{lifetime in years})$$

For inhalation exposures, this yields the Adjusted Concentration:

$$\text{Adjusted Concentration} = \text{Concentration} * (\text{exposure period} / \text{lifetime})$$

Typically (and in **RISK*ASSISTANT**), the adjusted concentration will also incorporate adjustments for differences between the actual exposure pattern and the assumed pattern of continuous lifetime exposure. For example, if exposure only occurred for one hour each day, the Adjusted Concentration would be only 1/24th of the concentration during that hour.

LADD = Lifetime Average Daily Dose.
Units are milligrams of contaminant per kilogram of body weight per day.

Adj.Inh.Conc = Adjusted Inhaled Concentration: Continuous concentration equivalent to exposure concentration; considering frequency and duration of exposure and inhalation rate.
Units are micrograms of contaminant per cubic meter.

Chemical Medium Scenario	Oral LADD mg/kg/d	Inhalation Adj. Concentration ug/cu m	Dermal LADD mg/kg/d
7440-38-2 ARSENIC AND COMPOUNDS			
Surface Water			
Drinking Water	3.4e-007		
Showering		Missing Data	7.8e-010
Indoor Air		Missing Data	
Outdoor Air		Missing Data	
Fish and Shellfish	4.0e-007		
Swimming	4.5e-010		2.1e-010
TOTALS	7.4e-007		9.8e-010

NOTE: scientific notation is used for numbers less than 0.000001 and greater than 1000000.
For example: $0.00000021 = 2.1 \times 10^{-7} = 2.1 / 10000000$ and $21000000 = 2.1 \times 10^7 = 2.1 * 10000000$.
ADD/LADD values are meaningful up to the second significant digit.

Carcinogenic Risk

For chemicals that may cause cancer if ingested, risk is calculated as a function of oral Slope Factor and Dose:

$$-(\text{Oral Slope Factor} * \text{Lifetime Average Daily Dose})$$

$$\text{Risk} = 1 - e$$

If the risk results from breathing the chemical, the calculation is based on concentration, rather than dose, as follows:

$$\text{Risk} = 1 - e^{-(\text{Unit Risk} \times \text{Concentration})}$$

$$\text{Risk} = 1 - e$$

For dermal exposures, the dose absorbed through the skin is used in combination with the oral slope factor, using the same equation that is used for calculating risks from oral exposures. This may lead to underestimation of dermal risk.

These estimates represent theoretical excess cancer risk (i.e. risk over background cancer incidence) of developing cancer. For example, if the calculated risk is 1 in 1,000,000 (1×10^{-6}), this would literally suggest that a person would have a one-in-a-million chance of getting cancer because of the specified chemical exposure, in addition to her/his chance of getting cancer from other causes.

- Oral Slope** = Slope of the (carcinogenic) dose-response function, in the low-dose, linear range. Used for oral and dermal exposures. Units are 1/(milligram of chemical per kilogram of body weight per day).
- Unit Risk** = Slope of the (carcinogenic) concentration-response function, in the low-concentration, linear range. Used for inhalation exposures. Units are 1/(micrograms of chemical per cubic meter of air).

Slope Factors and Unit Risks are generally estimated as the 95th percentile confidence limits using the linearized multistage model, when based on animal data (estimates derived from studies in humans often employ mathematical best estimates). As such, they are conservative estimates of toxic hazard. Risks estimated by combining these hazard values with exposure estimates are commonly referred to as upper-bound risks, but because exposure estimates may not represent upper-bound estimates, risk estimates are not true upper-bound risks.

- Weight of Evidence** = EPA class designating overall strength of evidence that a substance causes cancer in humans.
- A = Known human carcinogen.
 - B1 = Probable human carcinogen, limited human data.
 - B2 = Probable human carcinogen, inadequate or no human data.
 - C = Possible human carcinogen.
 - D = Not classifiable as human carcinogen.
 - E = Evidence that not carcinogenic in humans.

Chemical Medium	Risk (Odds): Individual Probability of Getting Cancer from this Exposure Alone		
	Oral Inhalation	Dermal	
7440-38-2 ARSENIC AND COMPOUNDS			
Weight of Evidence: A	Unit Risk($1/(\mu\text{g}/\text{m}^3)$): 0.0043	Source: IRIS(05/30/95)	
Surface Water			
Drinking Water	Missing Slope		
Showering	Missing Data	Missing Slope	
Indoor Air	Missing Data		
Outdoor Air	Missing Data		
Fish and Shellfish	Missing Slope		
Swimming	Missing Slope	Missing Slope	
MEDIUM TOTALS			
ALL MEDIA TOTALS			

NOTE: scientific notation is used for completeness.

For example: $0.00000021 = 2.1 \times 10^{-7} = 2.1 / 10,000,000$ (odds of 2 in 10,000,000) and $21,000,000 = 2.1 \times 10^7 = 2.1 \times 10,000,000$.

It is generally assumed that carcinogenic risk is zero only when exposure is zero, and that at low doses, the relationship between dose and response can be approximated by a straight line.

These estimates represent the theoretical excess cancer risk (i.e. risk over background

cancer incidence) of developing cancer. For example, if the calculated risk is 0.000001 (1 e-006), this would literally suggest that a person would have a one-in-a-million chance of getting cancer because of the specified chemical exposure, in addition to her/his chance of getting cancer from other causes. However, in view of the large uncertainties associated with such risk estimates, they should always be interpreted as general indicators, rather than precise estimates. EPA generally considers risks below 1 in a 1,000,000 (1e-6) to be low.

Because toxicity data from studies using dermal exposure are generally not available, Slope Factors from studies using oral exposures are usually employed to assess risks from dermal exposures. However, because oral toxicity data generally represent administered dose, while dermal exposure evaluation provides estimates of absorbed dose, risk estimates for dermal exposure may underestimate the actual risks of dermal exposure. This reflects the fact that the absorbed dose in an oral toxicity study may be significantly less than the administered dose. When an assessor has information on the pharmacokinetics of a chemical, it is appropriate to adjust for differences between oral and dermal absorption in the calculation of risks from dermal exposure. The procedures employed in this version of **RISK*ASSISTANT** assume complete absorption of orally administered doses. Appendix A of the Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part A) (EPA/540/1-89/002, December, 1989) contains a discussion of appropriate adjustment procedures.

Hazard Quotient

For agents that cause non-cancer toxic effects, a Hazard Quotient (H.Q.) is calculated, which compares the expected exposure to the agent to an exposure that is assumed not to be associated with toxic effects.

For oral or dermal exposures, the Average Daily Dose (ADD) is compared to a Reference Dose (RfD):

$$H.Q. = \text{Average Daily Dose} / \text{Reference Dose}$$

For inhalation exposures, the inhaled concentration is compared to a Reference Concentration (RfC):

$$H.Q. = \text{Inhaled Concentration} / \text{Reference Concentration}$$

An effort is made to ensure that Reference Doses and Reference Concentrations provide a conservative estimate of non-cancer toxic hazards. The uncertainty factors applied to toxicity data are intended to take into account differences in sensitivity to toxic effects within and between species, and differences in toxic effects between chronic and subchronic exposures.

Definitions of abbreviations employed in this table:

- RfC** =Reference Concentration (inhaled concentration not associated with toxicity).
Units are milligrams of contaminant per cubic meter of air.
- RfD** =Reference Dose (daily dose not associated with toxicity).
Units are milligrams of contaminant per kilogram of body weight per day.

Chemical Medium	Hazard Quotient: Ratio of Average Dose to 'Safe' Daily Dose		
	Oral Scenario	Inhalation	Dermal
7440-38-2 ARSENIC AND COMPOUNDS	RfD (mg/kg/d): 0.0003	No RfC	Source: IRIS(05/30/95)
Surface Water			
Drinking Water	0.002621		
Showering		Missing Data	0.000006
Indoor Air		Missing Data	
Outdoor Air		Missing Data	
Fish and Shellfish	0.003114		
Swimming	0.000004		0.000002
MEDIUM TOTALS	0.005738		0.000008
ALL MEDIA TOTALS	0.005738		0.000008

NOTE: scientific notation is used for completeness.

For example: 0.00000021 = 2.1e-7 = 2.1 / 10,000,000 (odds of 2 in 10,000,000) and 21,000,000 = 2.1e7 = 2.1 * 10,000,000.
HQ/HI values are meaningful up to the first significant digit.

It is generally assumed that non-cancer toxic effects have some threshold. That is, up to some finite level of exposure, physiological defense mechanisms ensure that no toxic effect will occur. Accordingly, hazard assessment for non-carcinogenic effects involve estimating an exposure that is less than this threshold level. This is done by applying "uncertainty factors" to exposures that appear to be near this threshold in laboratory toxicology studies. This yields a Reference Dose (RfD) for oral exposures, or a Reference Concentration (RfC) for inhalation exposures.

Because toxicity data from studies using dermal exposure are generally not available, Reference Doses from studies using oral exposures are usually employed to assess risks from dermal exposures. However, because oral toxicity data generally represent administered dose, while dermal exposure evaluation provides estimates of absorbed dose, risk estimates for dermal exposure may underestimate the actual risks of dermal exposure. This reflects the fact that the absorbed dose in an oral toxicity study may be significantly less than the administered dose. When an assessor has information on the pharmacokinetics of a chemical, it is appropriate to adjust for differences between oral and dermal absorption in the calculation of risks from dermal exposure. The procedures employed in this version of **RISK*ASSISTANT** assume complete absorption of orally administered doses. Appendix A of the *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part A)* (EPA/540/1-89/002, December, 1989) contains a discussion of appropriate adjustment procedures.

As noted above, H.Q.s for dermal exposures compare absorbed doses to oral RfDs that were derived from administered doses. Even if one does not take into account the possibility of route-specific toxic effects that would be overlooked by this procedure, it is important to remember that this may lead to the underestimation of risks from dermal exposures.

TOTALS FOR ALL CHEMICALS

	<u>Hazard Quotient</u>	<u>Risk (Odds): Individual Probability of Getting Cancer from this Exposure Alone</u>
Oral	0.005738	
Dermal	0.000008	
Surface Water	0.005746	

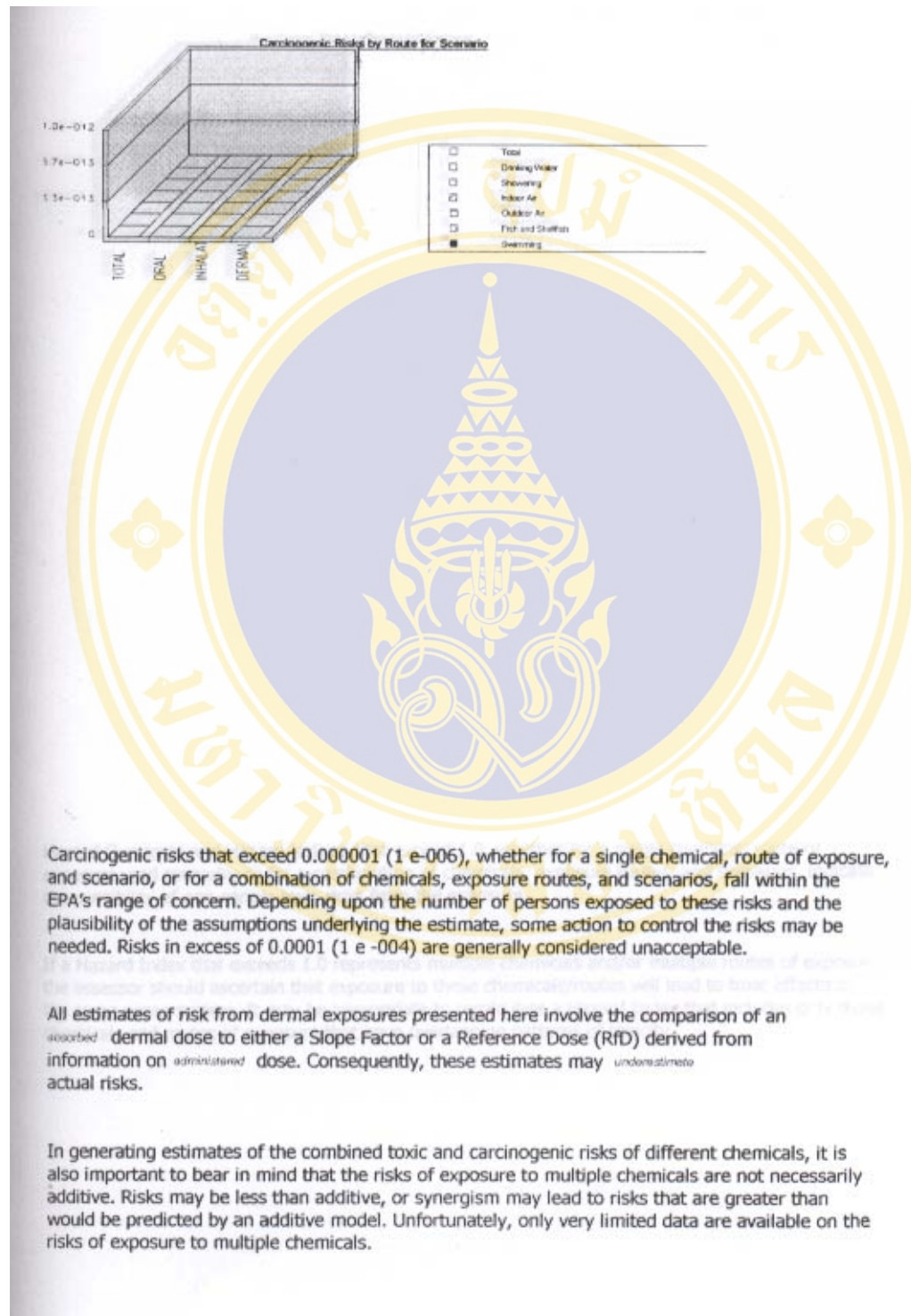
NOTE: scientific notation is used for completeness.

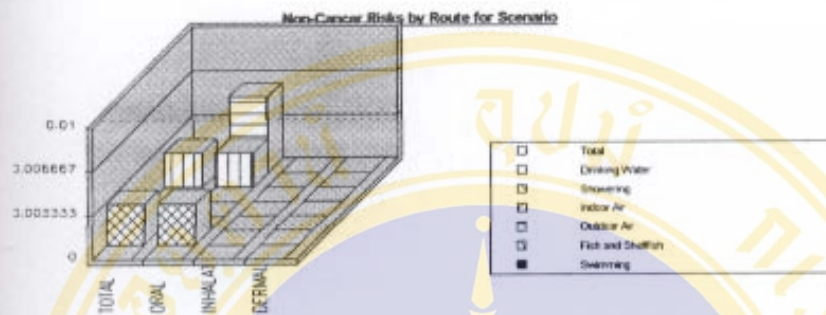
For example: $0.00000021 = 2.1 \times 10^{-7} = 2.1 / 10,000,000$ (odds of 2 in 10,000,000) and $21,000,000 = 2.1 \times 10^7 = 2.1 * 10,000,000$. HQ/HI values are meaningful up to the first significant digit.

In some situations, it is appropriate for the user to calculate combined risks from multiple chemicals and multiple routes of exposure. Many chemicals will produce the same toxic effect, regardless of the exposure route. For chemicals that cause cancer by several routes of exposure, the combined risk from all routes may be more informative than route-specific risk estimates, unless there is evidence that carcinogenic risks from different routes reflect different mechanisms of action. Similarly, for non-cancer toxic effects, differences between routes may only affect toxic potency, which will be reflected in the use of route-specific Reference Doses or Reference Concentrations.

Carcinogenic risk estimates for particular chemicals and routes of exposure may be summed directly to produce an estimate of total carcinogenic risk. Similarly, Hazard Quotients for chemicals that produce toxic effects in the same organ system may be summed to yield a Hazard Index. Hazard Indices < 1.0 are generally considered by EPA to be associated with low risks on non-cancer toxic effects.

In generating estimates of the combined toxic and carcinogenic risks of different chemicals, it is also important to bear in mind that the risks of exposure to multiple chemicals are not necessarily additive. Risks may be less than additive, or synergism may lead to risks that are greater than would be predicted by an additive model. Unfortunately, only very limited data are available on the risks of exposure to multiple chemicals.





Hazard Quotients and Hazard Indices that exceed 1.0, whether for a single chemical, route of exposure, and scenario, or for a combination of chemicals, exposure routes, and scenarios, indicate the possibility of non-cancer toxic risks from the exposure.

If a Hazard Index that exceeds 1.0 represents multiple chemicals and/or multiple routes of exposure, the assessor should ascertain that exposure to these chemicals/routes will lead to toxic effects in the same organ system. It may be appropriate to recalculate a Hazard Index that includes only those chemicals and routes of exposure that have overlapping patterns of toxicity.

BIOGRAPHY

Name	Major Saranyu Viriyavejakul
Date of Birth	25 September 1969
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