

TABLES OF CONTENTS

| | Page |
|--|------|
| ACKNOWLEDGMENTS | iii |
| ABSTRACT IN THAI | iv |
| ABSTRACT IN ENGLISH | vi |
| LIST OF TABLES | xi |
| LIST OF FIGURES | xii |
| CHAPTER 1 INTRODUCTION | 1 |
| 1.1 Introduction | 1 |
| 1.2 Literature Review | 1 |
| 1.3 Objectives of this study | 5 |
| 1.4 Area and method of study | 6 |
| 1.5 Methodology and scope of this study | 9 |
| 1.5.1 Field measurements phase | 9 |
| 1.5.2 Processing and analysis phase | 10 |
| 1.6 Usefulness of the research | 11 |
| CHAPTER 2 PRINCIPLE AND THEORY | 12 |
| 2.1 The origins of radon | 12 |
| 2.2 Migration of radon in overburden | 14 |
| 2.2.1 Radon diffusion equations | 15 |
| 2.2.2 Radon diffusion plus fluid flow equation | 16 |
| 2.3 Theory of soil-gas permeability measurement | 16 |
| CHAPTER 3 MEASURING METHODS AND RESULTS | 19 |
| 3.1 Time-integrated measurements of indoor radon concentrations using unfiltered track detectors | 19 |
| 3.2 Grab sampling measurements of indoor and soil-gas radon concentrations | 24 |
| 3.3 Relative soil-gas permeability measuring method | 33 |

| | |
|--|----|
| CHAPTER 4 PROCESSING AND ANALYSIS | 38 |
| 4.1 Soil-gas radon and indoor radon concentrations | 38 |
| 4.2 House classification | 43 |
| 4.3 Indoor radon concentration and soil-gas radon concentration at 0.5-meter and 1.0-meter depths in relation to winter and summer and to house type | 45 |
| 4.3.1 Indoor radon concentration and soil-gas radon concentration at 0.5-meter depth in winter and summer correlated to house type | 45 |
| 4.3.2 Indoor radon concentration and soil-gas radon concentration at 1.0-meter depth in winter and summer correlated to house type | 47 |
| 4.4 Winter and summer indoor radon concentrations and soil-gas permeability at 0.5-meter and 1.0-meter depths in relation to house type | 51 |
| 4.4.1 Winter and summer indoor radon concentration and soil-gas permeability at a 0.5-meter depth correlated with house type | 51 |
| 4.4.2 Winter and summer indoor radon concentration and soil-gas permeability at a 1.0-meter depth correlated with house type | 53 |
| 4.5 Winter and summer indoor radon concentration and product of soil-gas radon concentration times soil-gas permeability at 0.5-meter and 1.0-meter depths in relation to house type | 56 |
| 4.5.1 Winter and summer indoor radon concentration and product of soil-gas radon concentration times soil-gas permeability at a 0.5-meter depth correlated with house type | 56 |
| 4.5.2 Winter and summer indoor radon concentration and product of soil-gas radon concentration times soil-gas permeability at a 1.0-meter depth correlated with house type | 59 |

| | | |
|-------------------------------------|--|-----|
| 4.6 | Winter and summer indoor radon concentration and thoron/radon ratio at 0.5-meter and 1.0-meter depths in relation to house types | 63 |
| 4.6.1 | Winter and summer indoor radon concentration and thoron/radon ratio at a 0.5-meter depth correlated with house type | 63 |
| 4.6.2 | Winter and summer indoor radon concentration and thoron/radon ratio at a 1.0-meter depth correlated with house types | 65 |
| 4.7 | Correlation between soil-gas radon concentration and soil-gas permeability for indoor radon prediction | 68 |
| 4.8 | The correlation between year-round average indoor radon and some of soil parameters at 0.5-meter in summer season for type IV houses | 71 |
| CHAPTER 5 DISCUSSION AND CONCLUSION | | 76 |
| 5.1 | Discussion | 76 |
| 5.2 | Conclusion | 79 |
| REFERENCES | | 80 |
| APPENDIX A | | 84 |
| APPENDIX B | | 95 |
| CURRICULUM VITAE | | 105 |

LIST OF TABLES

| Table | Page |
|---|-------------|
| 1.1 Legend of rock | 9 |
| 4.1 Table of the number of houses in radon risk diagram | 71 |

LIST OF ILLUSTRATIONS

| Figure | Page |
|--|------|
| 1.1 Map of Amphoe Doi Tao, showing the study area | 6 |
| 1.2 Study area and locations of surveyed houses (The number shown in the map are house's ID number) | 7 |
| 1.3 Geological map of Amphoe Doi Tao | 8 |
| 1.4 A sample of radon risk diagram (Surbeck, 1993) | 10 |
| 2.1 Decay scheme for naturally occurring ^{238}U chain | 13 |
| 2.2 Decay scheme for naturally occurring ^{232}Th chain | 13 |
| 3.1 Unfiltered track preparation | 19 |
| 3.2 Equipment used to etch detector | 20 |
| 3.3 PC monitor view of a 4-square millimeter cellulose nitrate detector | 21 |
| 3.4 Equipment used for enlarging cellulose nitrate detector film | 21 |
| 3.5 Time-integrated indoor radon concentrations from 40 houses during three seasons | 23 |
| 3.6 Schematic diagram for measuring an indoor radon grab sample | 25 |
| 3.7 Winter indoor radon concentration in the base house | 26 |
| 3.8 Summer indoor radon concentration in the base house | 26 |
| 3.9 Sequence of operations used to position the needle probe in a borehole. | 27 |
| 3.10 Schematic diagram of the soil-gas radon extraction system | 28 |
| 3.11 Boreholes positions | 29 |
| 3.12 Grab sample soil-gas radon concentrations at the base house in the winter season | 30 |
| 3.13 Grab sample soil-gas radon concentrations at base house in the summer season | 30 |
| 3.14 Grab sample soil-gas radon concentrations at 0.5-meter depth | 31 |
| 3.15 Grab sample soil-gas radon concentrations at 1.0-meter depth | 32 |

| | | |
|------|---|----|
| 3.16 | Schematic positioning of a perforated cylindrical probe buried in soil. | 33 |
| 3.17 | Arrangement of pump and its connection to the perforated probe for making relative soil-gas permeability measurements | 34 |
| 3.18 | Soil-gas permeability of 40 houses at 0.5-meter depth in winter and summer | 36 |
| 3.19 | Soil-gas permeability of 40 houses at 1.0-meter depth in winter and summer | 37 |
| 4.1 | Winter indoor radon concentration and soil-gas radon concentration at a 0.5-meter depth. | 39 |
| 4.2 | Winter indoor radon concentration and soil-gas radon concentration at a 1.0-meter depth. | 40 |
| 4.3 | Summer indoor radon concentration and soil-gas radon concentration at a 0.5-meter depth. | 41 |
| 4.4 | Summer indoor radon concentration and soil-gas radon concentration at a 1.0-meter depth. | 42 |
| 4.5 | A sample of type I houses | 43 |
| 4.6 | A sample of type II houses | 44 |
| 4.7 | A sample of type III houses | 44 |
| 4.8 | A sample of type IV houses | 45 |
| 4.9 | Winter indoor radon concentration versus soil-gas radon concentration at a 0.5-meter depth. | 46 |
| 4.10 | Summer indoor radon concentration versus soil-gas radon concentration at a 0.5-meter depth. | 47 |
| 4.11 | Winter indoor radon concentration versus soil-gas radon concentration at a 1.0-meter depth. | 48 |
| 4.12 | Summer indoor radon concentration versus soil-gas radon concentration at a 1.0-meter depth. | 49 |
| 4.13 | Indoor radon versus soil-gas radon concentration in winter and summer | 50 |
| 4.14 | Winter indoor radon concentration versus soil-gas permeability at a 0.5-meter depth. | 52 |

| | | |
|------|--|----|
| 4.15 | Summer indoor radon concentration versus soil-gas permeability at a 0.5-meter depth. | 53 |
| 4.16 | Winter indoor radon concentration versus soil-gas permeability at a depth of 1.0 meter. | 54 |
| 4.17 | Summer indoor radon concentration versus soil-gas permeability at a 1.0-meter depth. | 55 |
| 4.18 | Indoor radon versus soil-gas permeability in winter and summer | 56 |
| 4.19 | Winter indoor radon concentration versus the product of soil-gas radon concentration times soil-gas permeability at a 0.5-meter depth. | 57 |
| 4.20 | Summer indoor radon concentration versus the product of soil-gas radon concentration times soil-gas permeability at a 0.5-meter depth. | 58 |
| 4.21 | Winter indoor radon concentration versus the product of soil-gas radon concentration times soil-gas permeability at a 1.0-meter depth. | 59 |
| 4.22 | Summer indoor radon concentration versus the product of soil-gas radon concentration times soil-gas permeability at a 1.0-meter depth. | 60 |
| 4.23 | Indoor radon versus product of soil-gas radon concentration times soil-gas permeability in winter and summer | 62 |
| 4.24 | Winter indoor radon concentration versus thoron/radon ratio at a 0.5-meter depth. | 63 |
| 4.25 | Summer indoor radon concentration versus thoron/radon ratio at a 0.5-meter depth. | 64 |
| 4.26 | Winter indoor radon concentration versus thoron/radon ratio at a 1.0-meter depth. | 65 |
| 4.27 | Summer indoor radon concentration versus thoron/radon ratio at a 1.0-meter depth. | 66 |
| 4.28 | Indoor radon versus thoron/radon ratio in winter and summer | 67 |
| 4.29 | Radon risk diagram of 0.5 meters depth in winter | 68 |

| | | |
|------|--|----|
| 4.30 | Radon risk diagram of 0.5 meters depth in summer | 69 |
| 4.31 | Radon risk diagram of 1.0 meters depth in winter | 69 |
| 4.32 | Radon risk diagram of 1.0 meters depth in summer | 70 |
| 4.33 | Soil-gas radon concentration and soil thoron/radon ratio versus radon flux (or indoor radon) for a set of diffusion coefficients | 72 |
| 4.34 | Year-round average indoor radon concentration versus soil-gas radon at 0.5-meter in summer | 73 |
| 4.35 | Year-round average indoor radon concentration versus thoron/radon at 0.5-meter in summer | 74 |
| 4.36 | Radon risk diagram of type IV houses. Data are summer values from 0.5-meter depth; number is year-round indoor radon indication | 75 |