NUREG/IA-0506

International Agreement Report

Using SNAP/RADTRAD and HABIT to Establish the Analysis Methodology for Maanshan PWR

Prepared by:
Jong-Rong Wang, Yu Chiang, Wen-Sheng Hsu, Hsiung-Chih Chen, Jung-Hua Yang, Chun-Kuan Shih, Shao-Wen Chen, Ting-Yi Wang*, Tzu-Yao Yu*

Nuclear and New Energy Education and Research Foundation;
Institute of Nuclear Engineering and Science, National Tsing Hua University
101 Section 2, Kuangfu Rd., Hsinchu, Taiwan

*Department of Nuclear Safety, Taiwan Power Company
242, Section 3, Roosevelt Rd., Zhongzheng District, Taipei, Taiwan

S. Bush-Goddard, NRC RAMP Project Manager
C. Sun, NRC HABIT Project Manager
J. Tomon, NRC SNAP/RADTRAD Project Manager

Division of Systems Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Manuscript Completed: March 2018
Date Published: January 2019

Prepared as part of
The Agreement on Research Participation and Technical Exchange
Under the Radiation Protection Computer Code Analysis and Maintenance Program (RAMP)

Published by
U.S. Nuclear Regulatory Commission

AVAILABILITY OF REFERENCE MATERIALS IN NRC PUBLICATIONS

NRC Reference Material

As of November 1999, you may electronically access NUREG-series publications and other NRC records at NRC's Public Electronic Reading Room at http://www.nrc.gov/reading-rm.html. Publicly released records include, to name a few, NUREG-series publications; *Federal Register* notices; applicant, licensee, and vendor documents and correspondence; NRC correspondence and internal memoranda; bulletins and information notices; inspection and investigative reports; licensee event reports; and Commission papers and their attachments.

NRC publications in the NUREG series, NRC regulations, and Title 10, "Energy," in the *Code of Federal Regulations* may also be purchased from one of these two sources.

1. The Superintendent of Documents
   U.S. Government Printing Office
   Mail Stop SSOP
   Washington, DC 20402–0001
   Internet: bookstore.gpo.gov
   Telephone: 202-512-1800
   Fax: 202-512-2250
2. The National Technical Information Service
   Springfield, VA 22161–0002
   www.ntis.gov
   1–800–553–6847 or, locally, 703–605–6000

A single copy of each NRC draft report for comment is available free, to the extent of supply, upon written request as follows:

Address: U.S. Nuclear Regulatory Commission
Office of Administration
Publications Branch
Washington, DC 20555-0001
E-mail: DISTRIBUTION.RESOURCE@NRC.GOV
Facsimile: 301–415–2289

Some publications in the NUREG series that are posted at NRC's Web site address http://www.nrc.gov/reading-rm/doc-collections/nuregs are updated periodically and may differ from the last printed version. Although references to material found on a Web site bear the date the material was accessed, the material available on the date cited may subsequently be removed from the site.

Non-NRC Reference Material

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, transactions, *Federal Register* notices, Federal and State legislation, and congressional reports. Such documents as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings may be purchased from their sponsoring organization.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at—

The NRC Technical Library
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852–2738

These standards are available in the library for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from—

American National Standards Institute
11 West 42nd Street
New York, NY 10036–8002
www.ansi.org
212–642–4900

Legally binding regulatory requirements are stated only in laws; NRC regulations; licenses, including technical specifications; or orders, not in NUREG-series publications. The views expressed in contractor-prepared publications in this series are not necessarily those of the NRC.

The NUREG series comprises (1) technical and administrative reports and books prepared by the staff (NUREG-XXXX) or agency contractors (NUREG/CR-XXXX), (2) proceedings of conferences (NUREG/CP-XXXX), (3) reports resulting from international agreements (NUREG/IA-XXXX), (4) brochures (NUREG/BR-XXXX), and (5) compilations of legal decisions and orders of the Commission and Atomic and Safety Licensing Boards and of Directors' decisions under Section 2.206 of NRC's regulations (NUREG-0750).

DISCLAIMER: This report was prepared under an international cooperative agreement for the exchange of technical information. Neither the U.S. Government nor any agency thereof, nor any employee, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for any third party's use, or the results of such use, of any information, apparatus, product or process disclosed in this publication, or represents that its use by such third party would not infringe privately owned rights.

NUREG/IA-0506

International Agreement Report

Using SNAP/RADTRAD and HABIT to Establish the Analysis Methodology for Maanshan PWR

Prepared by:
Jong-Rong Wang, Yu Chiang, Wen-Sheng Hsu, Hsiung-Chih Chen, Jung-Hua Yang, Chun-Kuan Shih, Shao-Wen Chen, Ting-Yi Wang*, Tzu-Yao Yu*

Nuclear and New Energy Education and Research Foundation;
Institute of Nuclear Engineering and Science, National Tsing Hua University
101 Section 2, Kuangfu Rd., Hsinchu, Taiwan

*Department of Nuclear Safety, Taiwan Power Company
242, Section 3, Roosevelt Rd., Zhongzheng District, Taipei, Taiwan

S. Bush-Goddard, NRC RAMP Project Manager
C. Sun, NRC HABIT Project Manager
J. Tomon, NRC SNAP/RADTRAD Project Manager

Division of Systems Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Manuscript Completed: March 2018
Date Published: January 2019

Prepared as part of
The Agreement on Research Participation and Technical Exchange
Under the Radiation Protection Computer Code Analysis and Maintenance Program (RAMP)

Published by
U.S. Nuclear Regulatory Commission

ABSTRACT

The objective of this study is to evaluate the control room (CR) habitability for the pressurized-water reactor (PWR) at the Maanshan nuclear power plant (NPP) site. The study focuses on the analysis methodology for CR habitability using the Symbolic Nuclear Analysis Package/RADionuclide, Transport, Removal And Dose Estimation (SNAP/RADTRAD) and the HABITability (HABIT) computer codes and is performed in two parts. In the first part of the analysis, the SNAP/RADTRAD computer code is used to develop models to evaluate the occupational radiation doses in the CR and the cumulative radiation doses at the exclusion area boundary (EAB), and low population zone (LPZ) during a loss-of-coolant accident (LOCA) design-basis accident (DBA). In the second part of the analysis, the HABIT code is used to evaluate the CR habitability during an accidental release of liquid carbon dioxide (CO_2) from a storage tank under burst conditions. Additionally during this step, the HABIT code results were compared with the results from the Areal Locations of Hazardous Atmospheres (ALOHA) computer code results. The results of the SNAP/RADTRAD code CR habitability analysis of the Maanshan NPP demonstrate that the occupational doses to the CR are below the requirements of General Design Criterion 19 (GDC-19), “Control Room,” of Appendix A to Title 10, Part 50 of the Code of Federal Regulations (10 CFR Part 50) and Chapter 6.4, “Control Room Habitability System,” Revision 3 of NUREG-0800, “Standard Review Plan,” (SRP). Additionally, the SNAP/RADTRAD code dose results for the EAB and LPZ demonstrate that they are below the criteria 10 CFR Part 100, “Reactor Site Criteria.” The results of the HABIT and ALOHA code evaluations of CR habitability of the Maanshan NPP following an accidental release of liquid CO_2 demonstrate that the results are below the U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide (RG) 1.78, “Evaluating the Habitability of a Nuclear Power Plant Control Room during a Postulated Hazardous Chemical Release,” toxicity limits. These results indicate that Maanshan NPP habitability can be maintained under the above conditions.

FOREWORD

The U.S. Nuclear Regulatory Commission (NRC) established the Radiation Protection Computer Code Analysis and Maintenance Program (RAMP) as part of their international cooperative research program in March of 2014. The purpose of RAMP is to develop, maintain, improve, distribute and provide training on NRC-sponsored radiation protection and dose assessment computer codes. RAMP computer codes encompass radiation protection and dose assessment in the areas of emergency response, decommissioning, environmental dose assessment and NPP licensing dose assessments (such as CR habitability). The American Institute in Taiwan (AIT) and Taipei Economic and Cultural Representative Office (TECRO) signed a RAMP agreement in 2016. The RAMP agreement allows the National Tsing Hua University (NTHU) of Taiwan to use the codes in RAMP. In this research, NTHU used the SNAP/RADTRAD and the HABIT computer codes to evaluate the CR habitability of the Maanshan NPP.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The Maanshan NPP is operated by Taiwan Power Company and is it the first PWR in Taiwan. The reactor is designed and built by the Westinghouse Company and has a rated core thermal power of 2822 MWt. Maanshan NPP has three loops in the reactor coolant system and each loop has a reactor coolant pump and a steam generator. The pressurizer is connected to the hot-leg piping in loop two. As a result of the events at the Fukushima Daiichi NPPs in Japan, the Institute of Nuclear Energy Research (INER) of the Atomic Energy Council (AEC) of Taiwan has taken steps to increase NPP safety requirements, especially in the area of CR habitability.

NTHU endeavored to evaluate the CR habitability of the Maanshan NPP using radiation protection and dose assessment codes in RAMP. NTHU used the SNAP/RADTRAD code to evaluate the occupational radiation doses in the CR and the cumulative radiation doses at the EAB and LPZ during a LOCA DBA. SNAP/RADTRAD is distributed in two parts: the SNAP Model Editor graphical user interface (GUI) with the RADTRAD plugin and the RADTRAD Analytical Code (RADTRAD-AC). The version SNAP/RADTRAD code used for this evaluation includes the SNAP Model Editor GUI version 2.51, RADTRAD Plugin version 4.11.2, and RADTRAD-AC version 4.5.3. Additionally, NTHU used the HABIT code is used to evaluate the CR habitability during an accidental release of liquid CO_2 from a storage tank under burst conditions. The version of the HABIT code used for this evaluation is HABIT version 2.0. Also during this step, the HABIT code results were compared with the results from the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (EPA) ALOHA computer code. The version of the ALOHA code used for this evaluation is ALOHA version 5.4.7.

The results of the SNAP/RADTRAD code CR habitability analysis of the Maanshan NPP demonstrate that the occupational doses to the CR are below the requirements of GDC-19 Appendix A to 10 CFR Part 50 and Chapter 6.4, Revision 3 of NUREG-0800. Additionally, the SNAP/RADTRAD code dose results for the EAB and LPZ demonstrate that they are below the reactor siting criteria of 10 CFR Part 100. The results of the HABIT and ALOHA code evaluations of CR habitability for the Maanshan NPP following an accidental release of liquid CO_2 demonstrate that the results are below RG 1.78 toxicity limits.

ABBREVIATIONS

AEC	Atomic Energy Council of Taiwan
AIT	American Institute in Taiwan
ALOHA	Areal Locations of Hazardous Atmospheres computer code
cfm	cubic feet per minute
CFR	Code of Federal Regulations
CHEM	chemical code
CO_2	carbon dioxide
CR	control room
DBA	design-basis accident
DCF	dose conversion factor
EAB	exclusion area boundary
EPA	U.S. Environmental Protection Agency
ESF	engineered safety features
EXTRAN	external transport code
FSAR	Final Safety Analysis Report
g/m^3	grams per cubic meter
GDC	general design criterion
GUI	graphical user interface
HABIT	Habitability computer code
INER	Institute of Nuclear Energy Research
LOCA	loss-of-coolant accident
LPZ	low population zone
m/s	meters per second
MWt	megawatt thermal
NOAA	National Oceanic and Atmospheric Administration
NPP	nuclear power plant
NRC	U. S. Nuclear Regulatory Commission
NUREG	U.S. Nuclear Regulatory Commission technical report designation
NTHU	National Tsing Hua University of Taiwan
PWR	pressurized-water reactor
RADTRAD	RADionuclide, Transport, Removal and Dose Estimation computer code
RADTRAD-AC	RADTRAD Analytical Code
RAMP	Radiation Protection Computer Code Analysis and Maintenance Program
RG	Regulatory Guide (NRC)
SNAP	Symbolic Nuclear Analysis Package
SRP	Standard Review Plan
TECRO	Taipei Economic and Cultural Representative Office
TEDE	total effective dose equivalent
% vol./d	percent volume per day

1 INTRODUCTION

The Maanshan nuclear power plant (NPP) is located in Hengchun Town, Pingtung County, Taiwan. Maanshan NPP is a pressurized-water reactor (PWR) operated by the Taiwan Power Company. The PWR at the Maanshan NPP is designed and manufactured by Westinghouse Company. The reactor coolant system is comprised of three loops with one reactor coolant pump and one steam generator in each loop. Additionally, the pressurizer is connected to the hot-leg piping in loop two, to maintain and adjust the pressure of the reactor coolant system.

In March 2011, following the Tohoku earthquake and subsequent the tsunami in Japan, several of the reactors and spent fuel pools at the Fukushima Daiichi NPP were damaged and resulted in the release of radioactive materials to the area surrounding the facility. These events caused in the Atomic Energy Council (AEC) of Taiwan to review and were necessary increase the safety requirements for NPPs in Taiwan.

The U.S. Nuclear Regulatory Commission (NRC) established the Radiation Protection Computer Code Analysis and Maintenance Program (RAMP) as part of their international cooperative research program in March of 2014. The purpose of RAMP is to develop, maintain, improve, distribute and provide training on NRC-sponsored radiation protection and dose assessment computer codes. RAMP computer codes encompass radiation protection and dose assessment in the areas of emergency response, decommissioning, environmental dose assessment and NPP licensing dose assessments (such as control room (CR) habitability). The American Institute in Taiwan (AIT) and Taipei Economic and Cultural Representative Office (TECRO) signed a RAMP agreement in 2016. The RAMP agreement allows the National Tsing Hua University (NTHU) of Taiwan to use the codes in RAMP. NTHU uses RAMP codes to develop and establish analysis methodologies for Taiwan NPPs including CR habitability.

NTHU used the Symbolic Nuclear Analysis Package/RADionuclide, Transport, Removal And Dose Estimation (SNAP/RADTRAD) code to evaluate the occupational radiation doses in the CR and the cumulative radiation doses at the exclusion area boundary (EAB), and low population zone (LPZ) during a loss-of-coolant accident (LOCA) design-basis accident (DBA). The SNAP/RADTRAD code calculates the transport and removal of radionuclides and dose at EAB, LPZ, and the control room during DBA, such as a LOCA, and is described in NUREG/CR-7220, "SNAP/RADTRAD 4.0: Description of Models and Methods" [1]. The CR, EAB and LPZ of Maanshan NPP are shown in Figure 1-1.

The results of the SNAP/RADTRAD code CR habitability analysis of the Maanshan NPP were compared to occupational dose requirements (i.e. total effective dose equivalent (TEDE), thyroid dose and beta skin dose) of General Design Criterion 19 (GDC-19), "Control Room," of Appendix A to Title 10, Part 50 of the Code of Federal Regulations (10 CFR Part 50) [2] and Chapter 6.4, "Control Room Habitability System," Revision 3 of NUREG-0800, "Standard Review Plan," (SRP) [3]. Additionally, the SNAP/RADTRAD code dose results for the EAB and LPZ were compared to the TEDE and thyroid dose requirements of 10 CFR Part 100, "Reactor Site Criteria," [4].

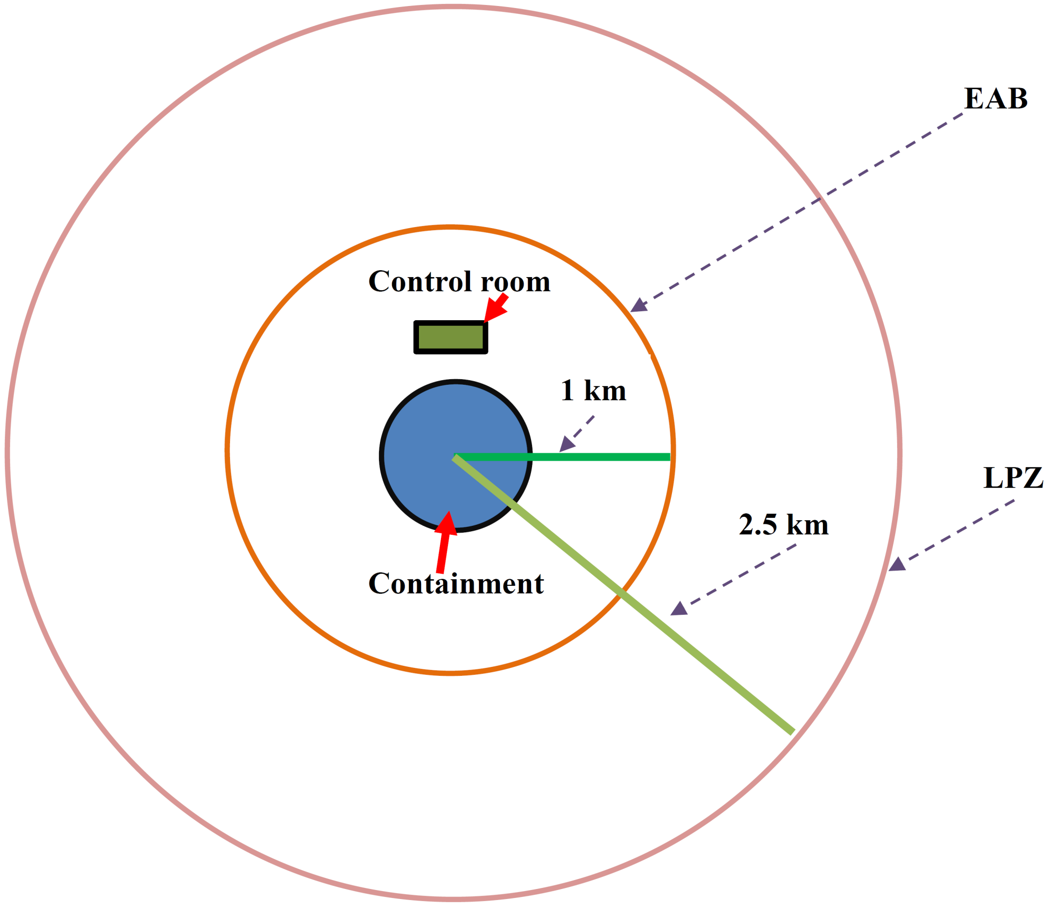


Figure 1-1 Locations of CR, EAB and LPZ for Maanshan NPP

Additionally, NTHU used the HABITability (HABIT) and the Areal Locations of Hazardous Atmospheres (ALOHA) computer codes to evaluate the CR habitability during a postulated hazardous chemical release of CO_2 from a storage tank under burst conditions. The HABIT computer code is a package of computer codes designed to assist in the evaluation of light-water reactor CR habitability in the event of accidental spills to release of airborne toxic chemicals. It consists of a number of program modules and produces files containing tabular output that can be printed, viewed, or imported as described in the "HABIT 2.0 User's Guide (Draft)" [5]. ALOHA is part of the Computer-Aided Management of Emergency Operated (CAMEO) software suite, which is developed jointly by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Environmental Protection Agency (EPA). ALOHA allows the user to estimate the spatial extent of volatile and flammable chemical clouds based on the toxicological and physical characteristics of the released chemical, atmospheric conditions, and specific circumstances of the release and is described NOAA Technical Memorandum NOS OR&R 43, "ALOHA® (Areal Locations of Hazardous Atmospheres) 5.4.4, Technical Documentation," [6]. ALOHA can also graphically display threat zones based on analysis results.

The results of the HABIT and ALOHA computer analyses of CR habitability of the Maanshan NPP, following an accidental release of liquid CO_2, were compared to the Table 1 values,

“Toxicity Limits (IDLH Limits) for Some Hazardous Chemicals, of Regulatory Guide (RG) 1.78, Revision 1, “Evaluating the Habitability of a Nuclear Power Plant Control Room during a Postulated Hazardous Chemical Release” [7]. The Table 1 CO_2 toxicity limit from reference [7] for CR habitability is 7.36 grams/cubic meter (g/m^3) of air, at standard temperature and pressure, based on CO_2 concentration 40,000 ppm.

2 METHODOLOGY AND ASSUMPTIONS

Figure 2-1 shows the CR habitability analysis methodology of Maanshan NPP. This analysis methodology has two parts: the assessment of radiation dose and exposure to toxic chemical concentrations. As shown in Figure 2-1 the first step in the process is the collection of technical data for the Maanshan NPP. The sources of this technical data include the Maanshan NPP Final Safety Analysis Report (FSAR), technical reports from the Institute of Nuclear Energy Research (INER) of the AEC of Taiwan references [8] through [12], and chemical and meteorological data. The radiation dose assessment portion of the CR habitability assessment is performed by developing SNAP/RADTRAD LOCA DBA models for Maanshan NPP and calculating doses at the CR, EAB and LPZ. The occupational dose results for the CR are then compared to the requirements of GDC-19 of Appendix A to 10 CFR Part 50 [2] and Chapter 6.4 of the SRP [3]. Likewise, the TEDE and thyroid doses calculated for the EAB and LPZ are then compared to the requirements 10 CFR Part 100 [4]. The second part of the CR habitability assessment required the screening of the Maanshan NPP for exposure to toxic chemical concentrations according to RG 1.78 [7]. Subsequently, a postulated hazardous chemical release of CO_2 from a storage tank under burst conditions is modeled using the HABIT code. The HABIT results are then compared to CO_2 toxicity limits in Table 1 of RG 1.78 [7] along with the ALOHA code predictions for the same event.

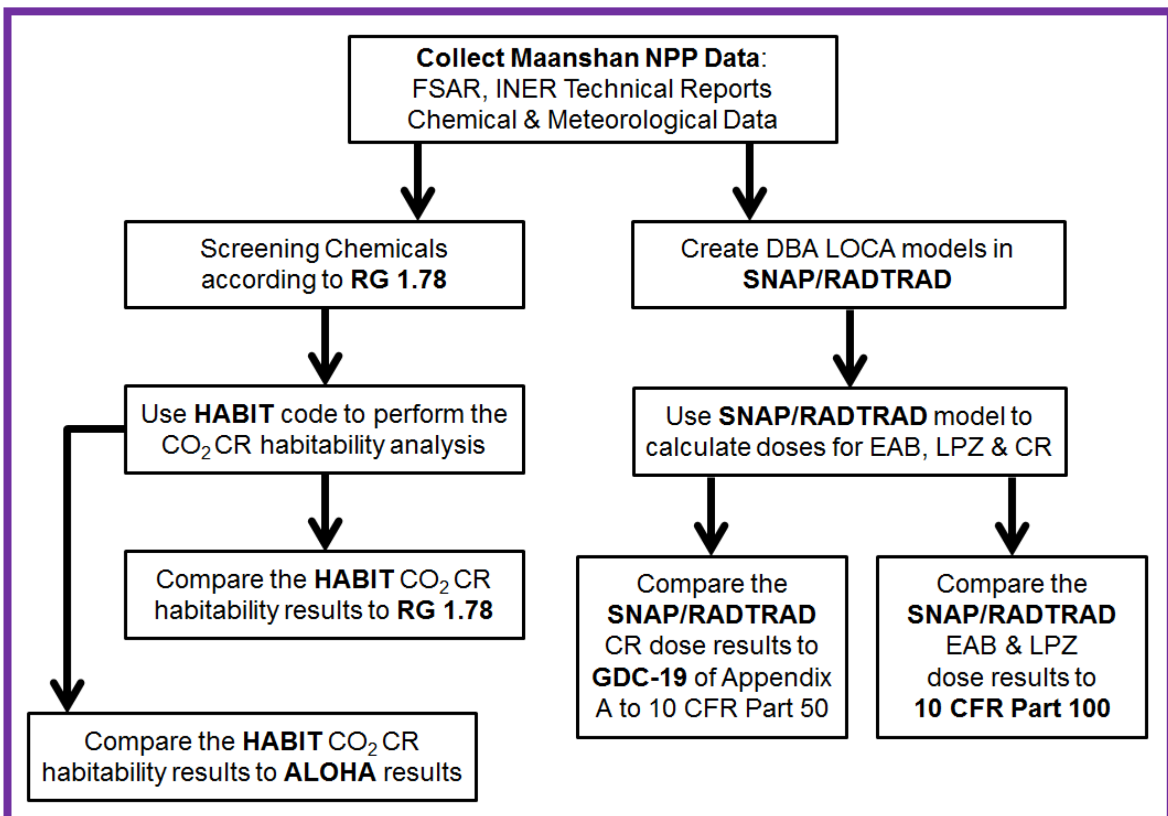


Figure 2-1 CR Habitability Analysis Methodology Flow Chart

2.1 SNAP/RADTRAD Modeling for Maanshan NPP

The SNAP/RADTRAD computer code is distributed in two parts: the SNAP Model Editor graphical user interface (GUI) with the RADTRAD plugin and the RADTRAD Analytical Code (RADTRAD-AC). The version SNAP/RADTRAD code used in this research includes the SNAP Model Editor GUI version 2.5.1, RADTRAD Plugin version 4.11.2, and RADTRAD-AC version 4.5.3. SNAP/RADTRAD allows the user to select either the Technical Information Document - 14844 (TID-14844), "Calculation of Distance Factors for Power and Test Reactor Sites," [13] or NUREG-1465, "Accident Source Terms for Light-Water Nuclear Power Plants," [14] or a user-defined source term. In SNAP/RADTRAD, radionuclides in various chemical forms are grouped into ten groups (Noble Gases, Halogens (iodine), Alkali Metals, Tellurium Group, Alkaline Earth Metals, Nobel Metals, Cerium Group, Lanthanides, Others and Non-Radioactive Aerosols) based upon their chemical and transport properties as noted in Table 4-2 of reference [1]. Additionally, the Halogens (iodine) group is further subdivided into three physical forms, which are elemental iodine, organic iodine, and aerosols. SNAP/RADTRAD also allows the user to model removal and reduction mechanisms, such as containment sprays, natural deposition, leakage, and filtration in the models flow pathways and compartments. Finally, SNAP/RADTRAD allows the user to input breathing rates (BR), atmospheric dispersion factors (χ/Q), and dose conversion factors for the CR, EAB and LPZ from the Maanshan NPP FSAR [7].

In the Maanshan NPP FSAR [7], the LOCA DBA case is assumed that a pipe of reactor coolant system ruptures with radionuclides released from the containment and/or engineered safety features (ESF). Other related assumptions are as follows:

For the containment leakage:

- The reactor core equilibrium iodine and noble gas inventories are based on long-term operation at 2,900 megawatt thermal (MWt).
- When the accident happens, 100 percent of the noble gas is released into the containment and immediately leaks from the containment to the environment.
- When the accident happens, 25 percent of the radioactive iodine inventory is released into the containment and immediately leaks from the containment to the environment.
- The iodine fission product inventory released to the containment is comprised of 91 percent elemental iodine, 5 percent particulate iodine, and 4 percent organic iodine.
- Credit for iodine removal by the containment spray system is simulated in this case.
- The efficiency of control room filter is 99 percent for iodine.

For the ESF leakage:

- The reactor core equilibrium iodine and noble gas inventories are based on long-term operation at 2900 MWt.
- When the accident occurs, 50 percent of the radioactive iodine inventory is released into the containment sump and leaks from the ESF to the environment.
- An iodine-water partition factor was conservatively taken as 0.1.

- When the accident occurs, 100 percent of the noble gas is released into the containment.
- The iodine fission product inventory released to the ESF is comprised of 97 percent elemental iodine and 3 percent is organic iodine.
- The efficiency of control room filter is 99 percent for iodine.

The SNAP/RADTRAD LOCA model for the containment leakage is presented in Figure 2-2. The establishment of the SNAP/RADTRAD LOCA model is based on Chapter 15 of the Maanshan NPP FSAR [7]. Figure 2-2 shows that compartment 1 is the environment, compartment 2 is the unsprayed area of the containment, compartment 3 is the sprayed area of the containment, and compartments 4 and 5 are the CR. Additionally, the volume of the containment is divided 81 percent into sprayed area (compartment 3) and 19 percent into the unsprayed area (compartment 2) with the intercrossing transfer rate between the two containment areas simulated by 33,000 cubic feet per minute (cfm). The compartments are connected via various pathways (leakage or flow) as shown in Figure 2-2. The leakage rate of the containment is assumed to be 0.1 percent volume per day (% vol./d) for days 0 to 1 and 0.05 % vol./d for days 1 to 30. The intake flow rate of the CR is 1,000 cfm and the TID-14844 [13] source term is used in this model.

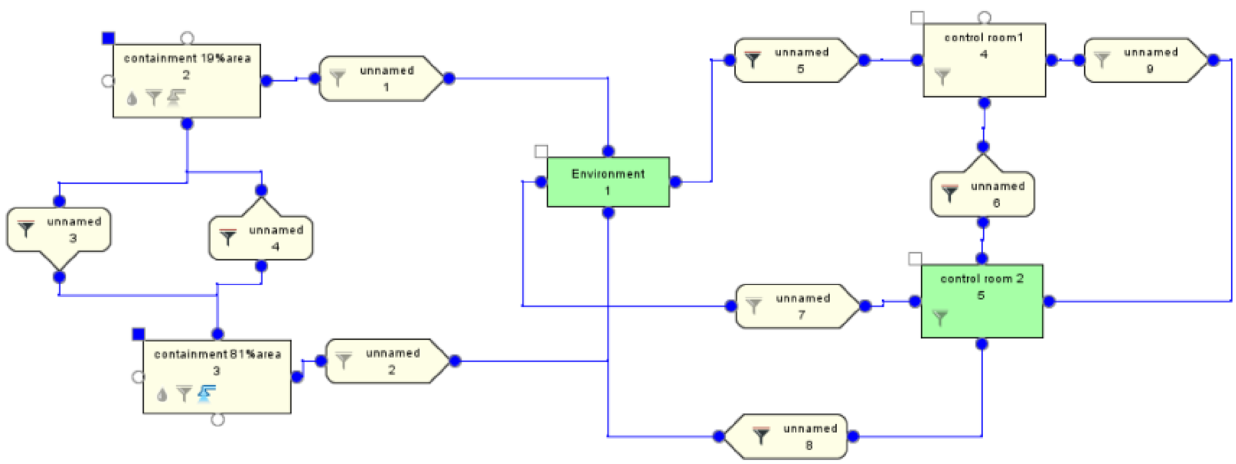


Figure 2-2 SNAP/RADTRAD LOCA Model for Maanshan NPP Containment Leakage

Figure 2-3 shows the SNAP/RADTRAD LOCA model for the ESF leakage. As mentioned above, this SNAP/RADTRAD LOCA model is based on Chapter 15 of the Maanshan NPP FSAR [7]. Figure 2-3 shows that compartment 1 is the environment, compartment 2 is the containment sump, and compartments 3 and 4 are the CR. The compartments are connected via various pathways (leakage or flow) as shown in Figure 2-3. The leakage rate of ESF is 0 cfm for the time frame of 0 to 32 minutes and 0.001943 cfm for the time frame of 32 minutes to 30 days. The intake flow rate of the CR is 1,000 cfm and the TID-14844 [13] source term of TID-14844 is used in this model.

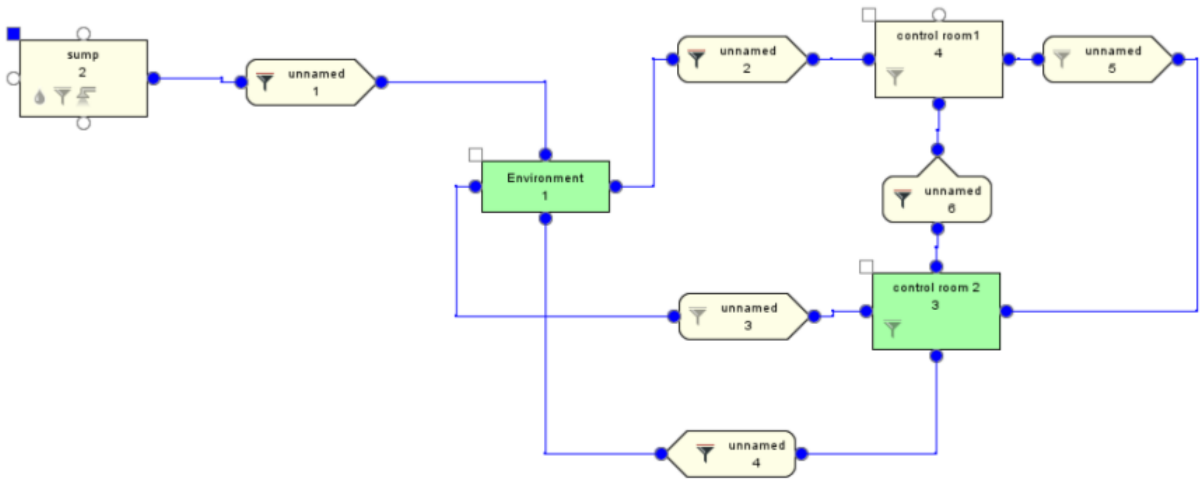


Figure 2-3 SNAP/RADTRAD LOCA Model for Maanshan NPP ESF Leakage

2.2 HABIT Model for Maanshan NPP

In accordance with the flow chart in Figure 2-1, the CR habitability assessment also requires the screening for exposure to toxic chemical concentrations according to RG 1.78 [7]. As referenced in the Maanshan NPP FSAR [7], the stationary stock of CO_2 at the site is 45,000 kilograms (kg), which is greater than the 45.35 kg stationary source limit in RG 1.78 [7]. The stationary stock of CO_2 at the Maanshan NPP cannot be screened out in accordance with RG 1.78 [7] as shown in Figure 2-4; therefore, a chemical concentration assessment for CR habitability for the liquid CO_2 storage tank burst scenario is performed by using the HABIT computer code.

The HABIT code version 2.0 is used in this research to evaluate the CR habitability in the event of accidental release and spills of toxic airborne chemicals. HABIT consists of a number of program modules and produces files containing tabular output that can be printed, viewed, or imported into spreadsheet programs for further applications. Figure 2-5 shows the HABIT main window with the two HABIT sub-modules (computer codes), external transport (EXTRAN) and chemical (CHEM) selected. However, HABIT version 2.0 has been extended and embedded with two independent dense-gas modules (i.e., Dense Gas Dispersion Model (DEGADIS) and the denser-than-air gaseous plume releases model (SLAB)) solving the effects of denser-than-air contaminant cloud. Therefore, there are four sub-modules that can be used to perform the evaluation of CR habitability for chemical toxicities. The introduction descriptions and flowchart for HABIT version 2.0 is available in reference [15]. For a hypothetical dense-gas releases, the transport behavior, and the associated potential impact of the CR air-intake height on the impact to the control room habitability is undergoing study.

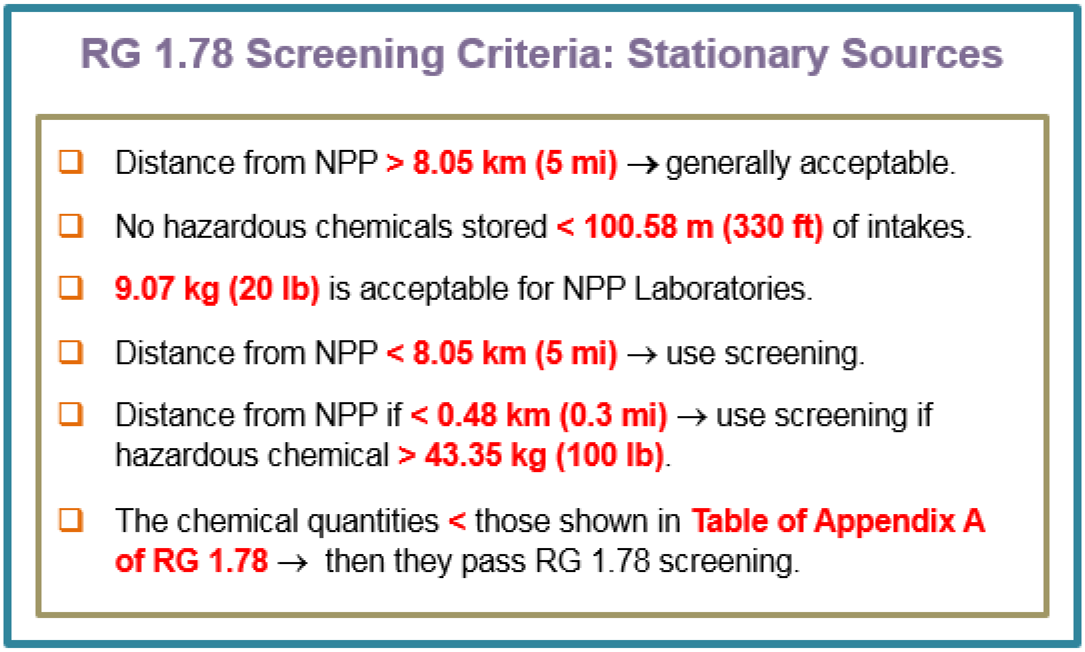


Figure 2-4 RG 1.78 Screening for Stationary Chemical Sources

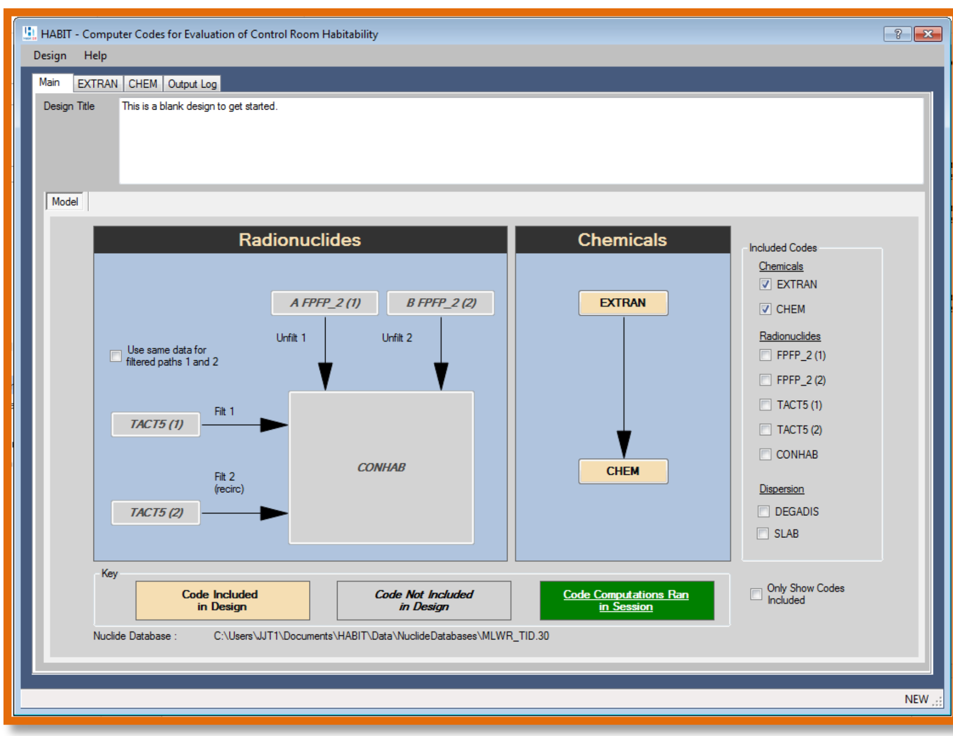


Figure 2-5 HABIT Main Window with EXTRAN and CHEM Tabs

Table 2-1 shows the HABIT input parameters and values for the liquid CO_2 storage tank burst scenario from reference [12]. The atmospheric stability classification is from RG 1.23, "Meteorological Monitoring Programs for Nuclear Power Plants," [16] and presented in Table 2-2. Additionally, sensitivity analyses of atmospheric parameters (wind speed, atmospheric stability classification, and air temperature) are also performed in this research.

Table 2-1 HABIT Input Parameters for the Liquid CO_2 Storage Tank Burst Scenario

Parameters	Values
CO_2 initial mass (kg)	45,000
CO_2 storage temperature (°C)	-16.67
Wind speed (m/s)	10
Atmospheric stability classification	D
Air temperature (°C)	30
Control room volume (m^3)	2,071.92
Control room intake flow rate (m^3/min)	28.32

Table 2-2 Atmospheric Stability Classification from RG 1.23

Stability Classification	Pasquill Stability Category
Extremely unstable	A
Moderately unstable	B
Slightly unstable	C
Neutral	D
Slightly stable	E
Moderately stable	F
Extremely stable	G

The HABIT computer code will first run EXTRAN sub-module (computer code). EXTRAN calculates the concentration of chemicals at the location of the CR air intake given information about the release and the environmental conditions. In this step, the chemical and meteorological data from references [8], [12] and [16] are input into the EXTRAN tab on the HABIT main window as shown in Figure 2-6. The model in EXTRAN is a Gaussian plume or puff dispersion model which allows longitudinal, lateral, and vertical dispersions. The model

also allows for the effect of wakes and for additional dispersion in the vertical direction when the distance between the release point and the CR is small.

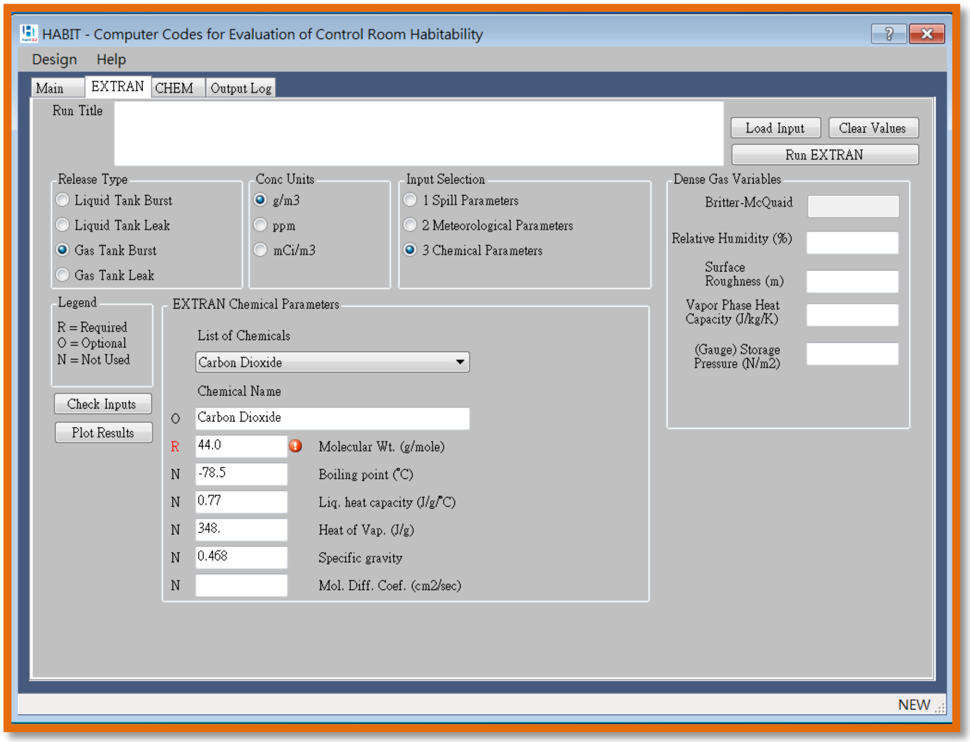


Figure 2-6 EXTRAN Tab on the HABIT Main Window

After the EXTRAN calculation is completed, the HABIT computer will run the CHEM sub-module (computer code). CHEM determines the chemical exposure to CR personnel by using the chemical concentrations calculated by EXTRAN and modeling the dilution factors of the chemical concentrations by ventilation flows (e.g. flow rates) in the CR. In this step, the flow rates from filtered, unfiltered, and bottled sources along with occupancy factors from references [8] and [12] are input into the CHEM tab on the HABIT main window as shown in Figure 2-7.

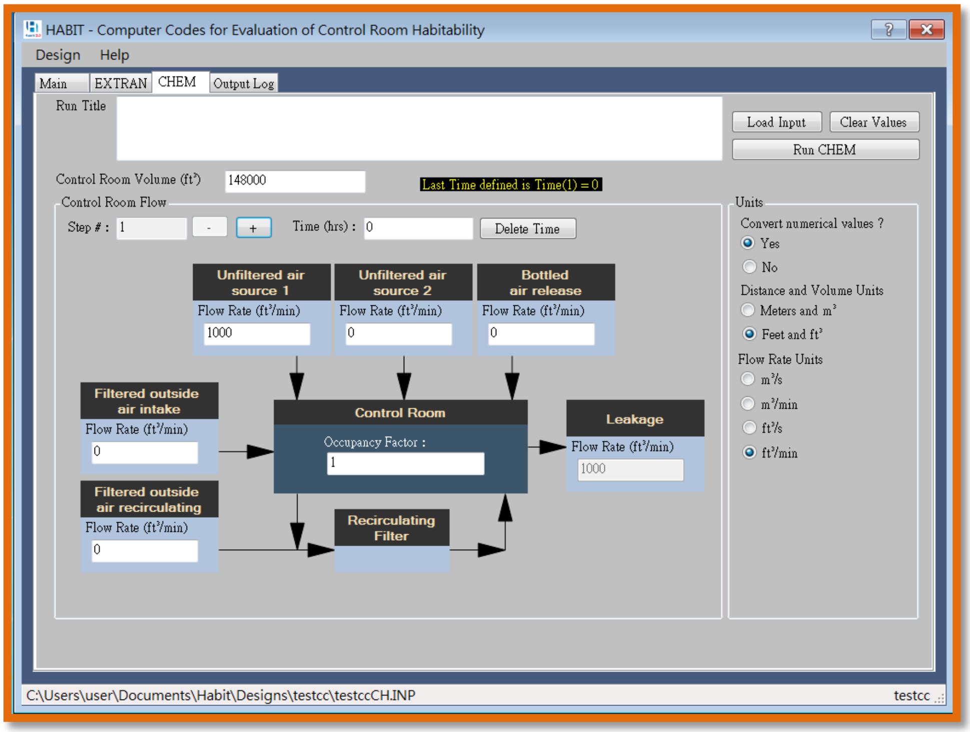


Figure 2-7 CHEM Tab on the HABIT Main Window

2.3 ALOHA Model for Maanshan NPP

The ALOHA code is an atmospheric dispersion model and it is part of the CAMEO software suite, which is developed jointly by the NOAA and the EPA. ALOHA allows the users to enter details about a real or potential chemical releases (e.g. downwind dispersion of a chemical cloud based on the toxicological/physical characteristics of the released chemical, atmospheric conditions, and specific circumstances of the release) to estimate the threats from the hazards associated with the release as noted in reference [6]. The HABIT CR habitability results are compared the ALOHA results in order to confirm the accuracy of HABIT in this research. The main differences between HABIT and ALOHA codes are as follows:

- The ALOHA code can estimate how a toxic cloud might disperse after a chemical release, which the HABIT code cannot.
- The ALOHA code is limited by the air exchange number to simulate CR intake rates; whereas, the HABIT code allows the user to actually enter CR leakage, personnel occupancy factors and CR recirculation in its analysis.

There are five main steps for the data entry in the ALOHA CR habitability analysis. The first step, is to enter the location data (e.g. elevation, latitude, and longitude) for the Maanshan NPP site as presented in Figure 2-8. Secondly, the CR building data for Maanshan NPP are entered in to ALOHA as shown in Figure 2-9. The value for the number of air change is calculated by the intake flow rate and volume of CR. In the third step, CO_2 is chosen in the Chemical Information screen as shown in Figure 2-10. In the fourth step, the atmospheric data (e.g. wind speed, air temperature, and humidity) are entered into ALOHA for the Maanshan site. Figure 2-11 shows the ALOHA Atmospheric Options screens with the Maanshan NPP

atmospheric data. Finally, the chemical source data type are entered into the ALOHA Direct Source screen as shown in Figure 2-12. Figure 2-13 shows the ALOHA Text Summary screen for the CR habitability analysis for the Maanshan NPP.

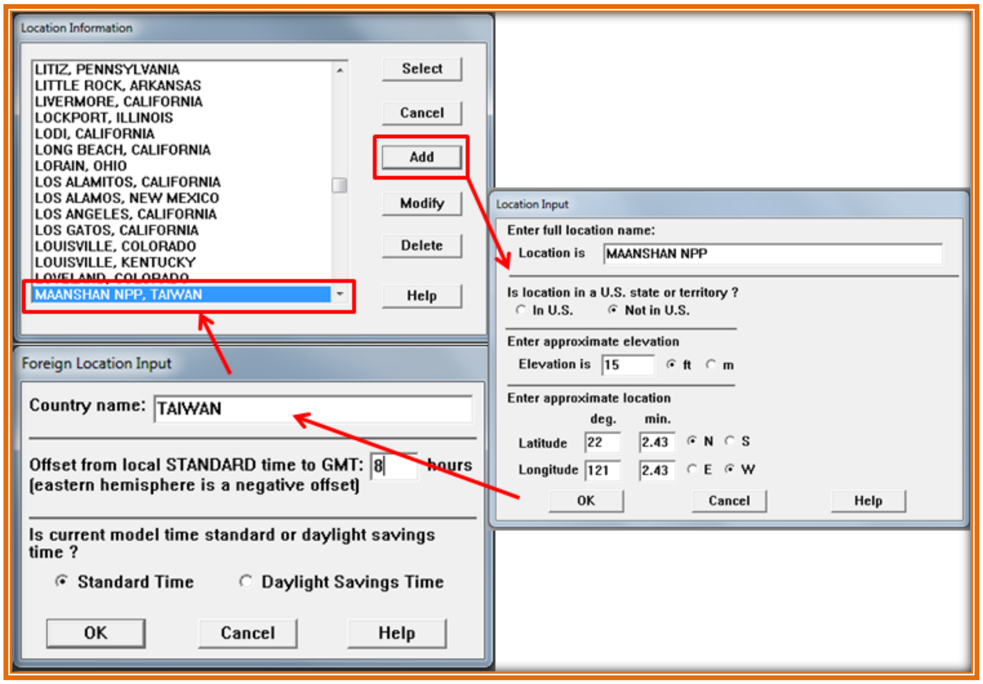


Figure 2-8 ALOHA Location Information Screens for Site Location Data

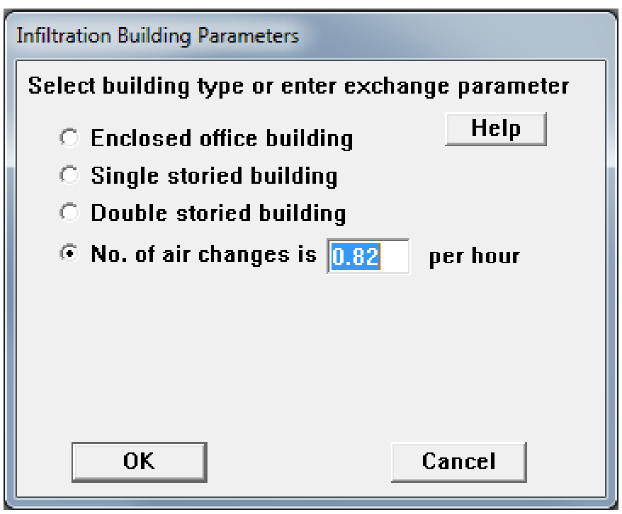


Figure 2-9 ALOHA Infiltration Building Parameters Screen

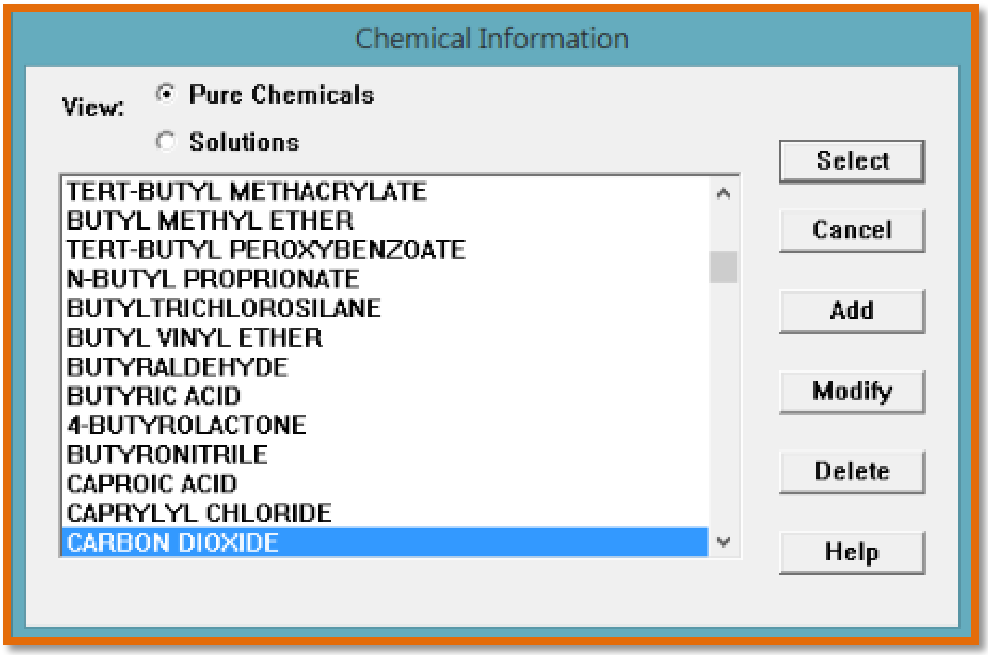


Figure 2-10 ALOHA Chemical Information Screen

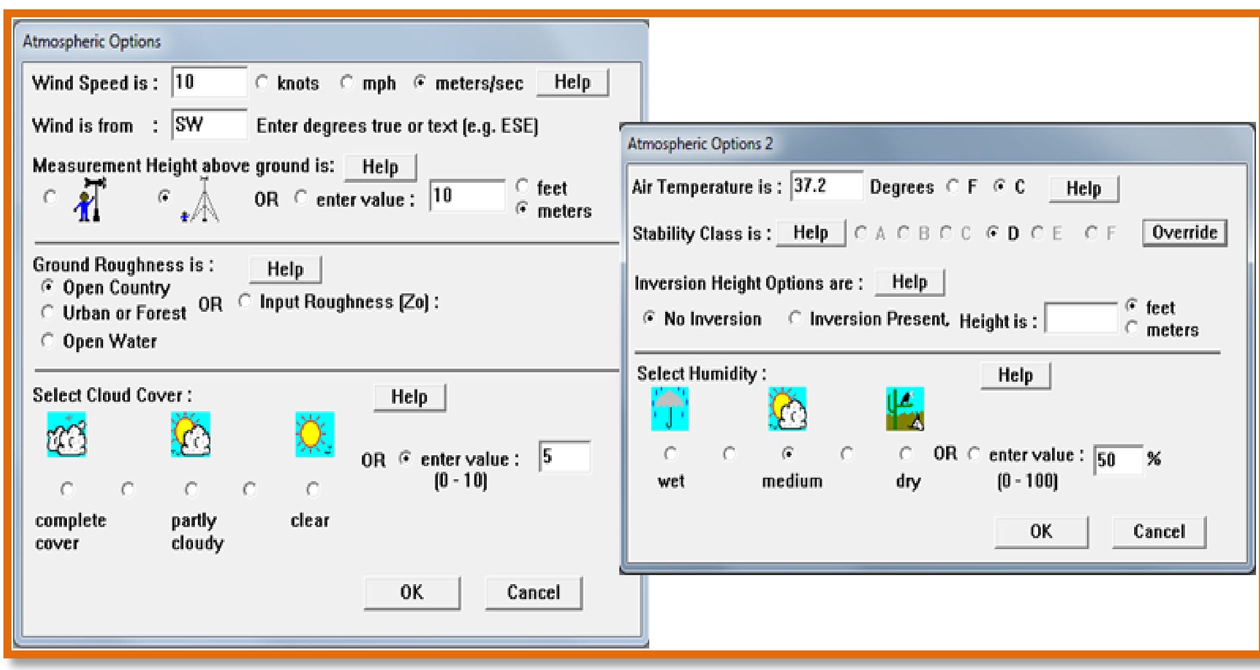


Figure 2-11 ALOHA Atmospheric Options Screens for Site Atmospheric Data

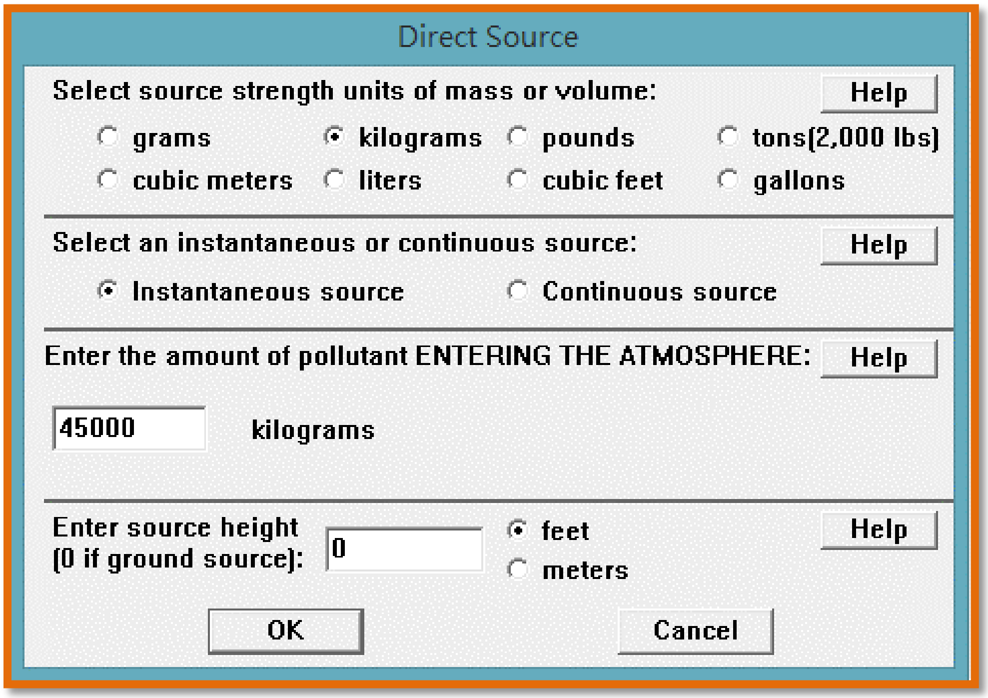
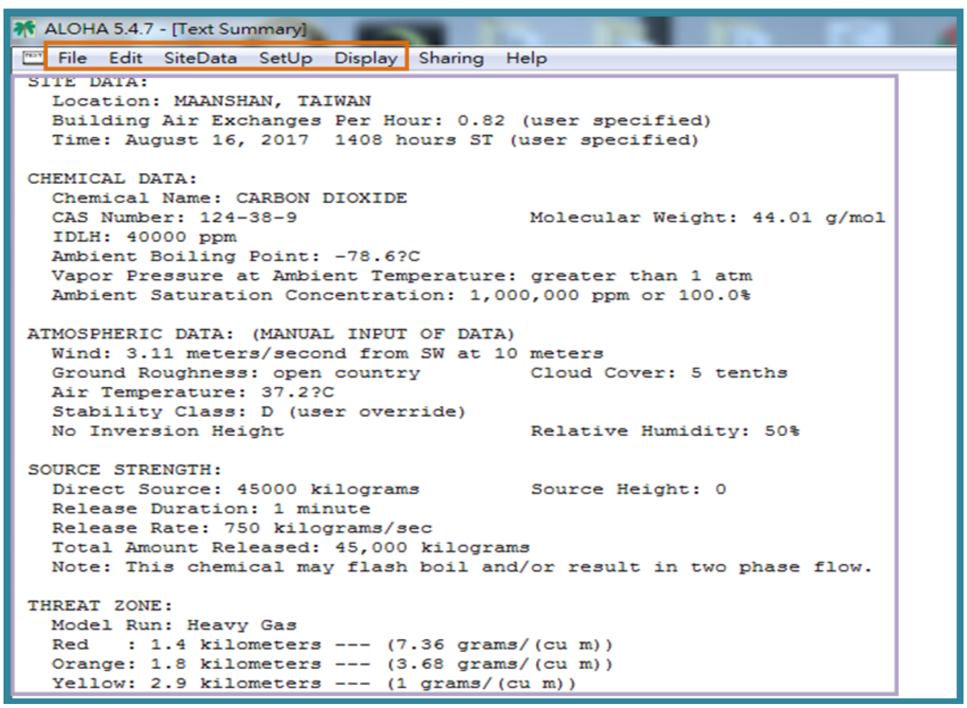


Figure 2-12 ALOHA Direct Source Screen for Chemical Source Data




```
SITE DATA:
  Location: MAANSHAN, TAIWAN
  Building Air Exchanges Per Hour: 0.82 (user specified)
  Time: August 16, 2017  1408 hours ST (user specified)

CHEMICAL DATA:
  Chemical Name: CARBON DIOXIDE
  CAS Number: 124-38-9                    Molecular Weight: 44.01 g/mol
  IDLH: 40000 ppm
  Ambient Boiling Point: -78.6?C
  Vapor Pressure at Ambient Temperature: greater than 1 atm
  Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

ATMOSPHERIC DATA: (MANUAL INPUT OF DATA)
  Wind: 3.11 meters/second from SW at 10 meters
  Ground Roughness: open country          Cloud Cover: 5 tenths
  Air Temperature: 37.2?C
  Stability Class: D (user override)
  No Inversion Height                     Relative Humidity: 50%

SOURCE STRENGTH:
  Direct Source: 45000 kilograms          Source Height: 0
  Release Duration: 1 minute
  Release Rate: 750 kilograms/sec
  Total Amount Released: 45,000 kilograms
  Note: This chemical may flash boil and/or result in two phase flow.

THREAT ZONE:
  Model Run: Heavy Gas
  Red   : 1.4 kilometers --- (7.36 grams/(cu m))
  Orange: 1.8 kilometers --- (3.68 grams/(cu m))
  Yellow: 2.9 kilometers --- (1 grams/(cu m))
```

Figure 2-13 ALOHA Text Summary Screen for Maanshan NPP

3 RESULTS

3.1 SNAP/RADTRAD Dose Assessment Results for Maanshan NPP

The SNAP/RADTRAD calculated occupational dose (TEDE, thyroid dose and beta skin) results for the CR habitability are compared to the requirements of GDC-19 of Appendix A to 10 CFR Part 50 [2] and Chapter 6.4 of the SRP [3]. Doses to an individual in the CR should not exceed the following criteria for any postulated DBA (reference [3]):

- TEDE of 50 mSv (5 rem).
- Thyroid dose 300 mSv (30 rem).
- Beta skin dose 300 mSv (30 rem).

Likewise, the calculated SNAP/RADTRAD dose (TEDE and thyroid dose) results for the EAB and LPZ are then compared to the reactor siting requirements of 10 CFR Part 100 [4]. These criteria are as follows:

For the EAB:

- A total radiation dose to the whole body is below a TEDE of 250 mSv (25 rem) for any 2 hour period following the onset of the postulated fission product release.
- A total radiation dose to the thyroid from iodine exposure is below 3,000 mSv (300 rem).

For the LPZ:

- A total radiation dose to the whole body is below a TEDE of 250 mSv (25 rem) during the entire period of the passage of the postulated fission product release.
- A total radiation dose to the thyroid from iodine exposure is below 3,000 mSv (300 rem) during the entire period of radioactive cloud passage.

3.1.1 CR Occupational Dose Results

Table 3-1 depicts the occupational dose analysis results of the SNAP/RADTRAD code for the CR. The analysis results of the SNAP/RADTRAD code are below the criteria in references [2] and [3]. However, there are some differences are between the SNAP/RADTRAD calculated doses and the Maanshan NPP FSAR [8]. The reasons which result in the differences are as follows:

- For TEDE, the value from the FSAR [8] is a summary value which includes; (1) whole body internal dose (i.e., committed effect dose equivalent (CEDE)) from the airborne radioactivity present in the CR, (2) direct whole body gamma dose from the radioactivity present in the containment building, and (3) direct whole body gamma dose from the radioactive cloud surrounding the CR. The SNAP/RADTRAD calculated dose does not include items 2 and 3.
- For the thyroid dose and beta skin dose, the value from the FSAR [8] is a summary value which contains the respective doses from containment and ESF leakage. However, the FSAR [8] does not list the values for the thyroid and beta skin dose from the containment and ESF leakage. Additionally, the FSAR [8] does not present the

activity data in the CR; therefore, it is suspected that the unknown FSAR data is the cause of the differences between the SNAP/RADTRAD results and the FSAR [8].

Table 3-1 SNAP/RADTRAD Results for the Maanshan NPP CR

	FSAR	SNAP/RADTRAD			Criteria
		Containment Leakage	ESF Leakage	Total	
TEDE (mSv)	19.5	10.4	2.2E-02	10.4	50
Thyroid dose (mSv)	270	175.2	17.8	193	300
Beta skin dose (mSv)	212	185.8	3.6E-01	186.1	300

3.1.2 EAB and LPZ Dose Results

Tables 3-2 and 3-3 show the calculated SNAP/RADTRAD TEDE and thyroid dose results for the EAB. Table 3-2 presents the comparison between the SNAP/RADTRAD calculated doses, the FSAR [8] doses, and criteria from 10 CFR Part 100 [4] for the containment leakage case. Table 3-3 shows the comparison between the SNAP/RADTRAD calculated doses, the FSAR [8] doses, and criteria from 10 CFR Part 100 [4] for the ESF leakage case. The SNAP/RADTRAD EAB TEDE and thyroid doses are consistent with the FSAR [8] data and are below the criteria of 10 CFR Part 100 [4].

Table 3-2 SNAP/RADTRAD Results for the Maanshan NPP EAB (containment leakage)

	FSAR	SNAP/RADTRAD	Criteria
TEDE (mSv)	9.9	9.8	250
Thyroid dose (mSv)	469	480.4	3,000

Table 3-3 SNAP/RADTRAD Results for the Maanshan NPP EAB (ESF leakage)

	FSAR	SNAP/RADTRAD	Criteria
TEDE (mSv)	5.2E-02	5.3E-02	250
Thyroid dose (mSv)	18.4	18.6	3,000

Tables 3-4 and 3-5 show the calculated SNAP/RADTRAD TEDE and thyroid doses results for the LPZ. Table 3-4 depicts the comparison between the SNAP/RADTRAD calculated dose, the FSAR [8] doses, and criteria from 10 CFR Part 100 [4] for the containment leakage case. Table 3-5 shows the comparison between the SNAP/RADTRAD calculated doses, the FSAR [8]

doses, and criteria from 10 CFR Part 100 [4] for the ESF leakage case. The SNAP/RADTRAD LPZ TEDE and thyroid doses are consistent with the FSAR [8] data and are below the criteria of 10 CFR Part 100 [4]. Therefore, the SNAP/RADTRAD models demonstrate a good accuracy and consistency according to the above comparisons. Figure 3-1 provides a graphical depiction of the SNAP/RADTRAD calculated EAB and LPZ doses for the containment leakage case.

Table 3-4 SNAP/RADTRAD Results for the Maanshan NPP LPZ (containment leakage)

	FSAR	SNAP/RADTRAD	Criteria
TEDE (mSv)	5.9	6.3	250
Thyroid dose (mSv)	629	646.9	3,000

Table 3-5 SNAP/RADTRAD Results for the Maanshan NPP LPZ (ESF leakage)

	FSAR	SNAP/RADTRAD	Criteria
TEDE (mSv)	6.9E-02	7.3E-02	250
Thyroid dose (mSv)	81.2	81.2	3,000

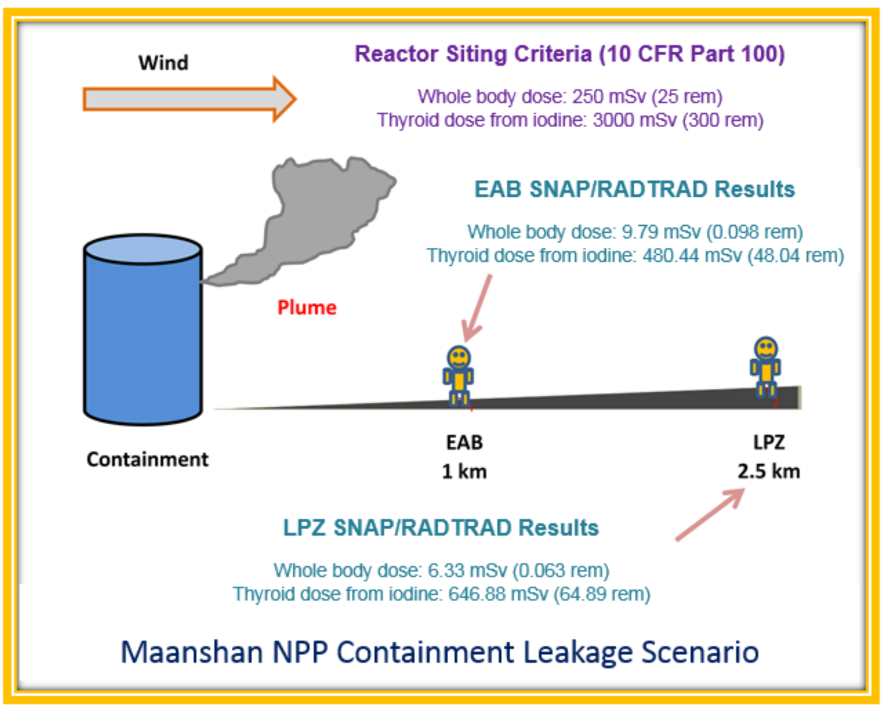


Figure 3-1 SNAP/RADTRAD Results for Maanshan NPP

3.2 HABIT and ALOHA Results for Maanshan NPP

The HABIT and ALOHA code results for the Maanshan NPP CR habitability during a postulated hazardous chemical release of CO_2 from a storage tank under burst conditions are shown in Table 3-6. The maximum HABIT CO_2 concentration in the CR is 0.96 g/m^3 which occurs at 26 seconds after the liquid CO_2 storage tank burst. The HABIT CO_2 concentration result is below the CO_2 toxicity limit from Table 1 of RG 1.78 [7] of 7.36 g/m^3. The HABIT result was also compared with the ALOHA result in this study. Table 3-6 also shows the ALOHA CO_2 concentration result, in the CR, of 4.06 g/m^3, which is also below the CO_2 toxicity limit from Table 1 of RG 1.78 [7]. Finally, the HABIT result is below the ALOHA result for a postulated hazardous chemical release of CO_2 from a storage tank under burst conditions.

Table 3-6 HABIT and ALOHA Code Results for Maanshan NPP

	Time (seconds)	Concentration (g/m^3)
HABIT	26	9.6E-01
ALOHA	-----	4.1
RG 1.78 Toxicity Limit	-----	7.36

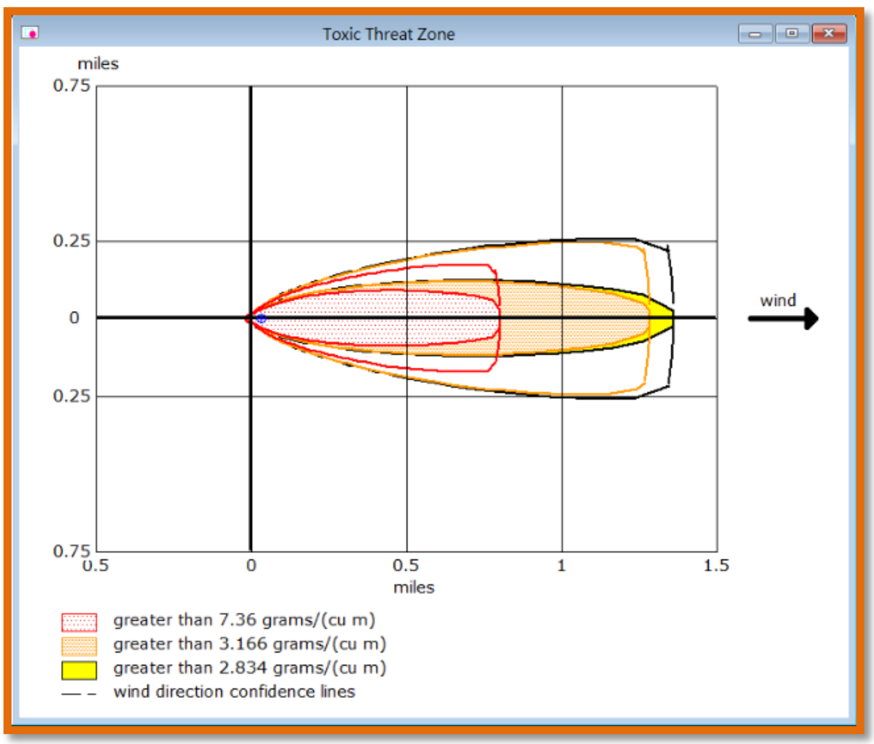


Figure 3-2 ALOHA Results for Maanshan NPP

Additionally, Figure 3-2 presents the ALOHA results for the toxic cloud range in the atmosphere. Three levels (7.36, 3.166, and 2.834 g/m^3) are in the dispersion range of CO_2 concentration. The range for 7.36 g/m^3 is about 0 to ~0.8 miles which is the hazard area.

Sensitivity analyses were also performed, in this research, of the atmospheric parameters of wind speed, atmospheric stability classification, and air temperature. Table 3-7 displays the results HABIT and ALOHA results for the wind speed sensitivity analysis. Four wind speed were chosen (5, 10, 20, and 30 meters per second (m/s)) for the wind speed sensitivity study. The maximum CO_2 concentration occurs at the 5 m/s case for both the ALOHA and HABIT codes. The 5 m/s HABIT CO_2 concentration result is 2.02 g/m^3 and the ALOHA CO_2 concentrations are 423 g/m^3 and 5.33 g/m^3 for the atmospheric and CR concentrations, respectively. When the wind speed is increased, the maximum CO_2 concentrations decreases in both codes. Finally, the HABIT CO_2 concentration results are below those calculated by ALOHA for all wind speeds.

Table 3-7 Sensitivity Study of Wind Speed for Maanshan NPP

Wind speed (m/s)	ALOHA Atmospheric Centerline Downwind Concentration (g/m^3)	ALOHA CR Concentration (g/m^3)	HABIT CR Concentration (g/m^3)
5	423	5.33	2.02
10	343	4.06	0.96
20	309	3.55	0.38
30	289	3.29	0.19

The atmospheric stability classification can be divided into seven classification levels (“A” through “G”) as noted in RG 1.23 [16] and shown in Table 2-2. The “A” level classification is extremely unstable with stability increasing down to level “G” level which is extremely stable. Table 3-8 displays the sensitivity study of atmospheric stability classification for three levels (A, D, and F). The maximum CO_2 concentration for both the HABIT and ALOHA codes occurs for “F” atmospheric stability classification. For the “F” atmospheric stability classification the HABIT CO_2 concentration is 1.53 g/m^3 and the ALOHA CO_2 concentrations are 373 g/m^3 and 4.49 g/m^3 for the atmospheric and CR concentrations, respectively. Additionally, when the atmospheric stability decreases the maximum CO_2 concentration decreases. Finally, the HABIT CO_2 concentration results are below those calculated by ALOHA for all atmospheric stability classifications.

Table 3-8 Sensitivity Study of Atmospheric Stability Classification for Maanshan NPP

Atmospheric Stability Classification	ALOHA Atmospheric Centerline Downwind Concentration (g/m^3)	ALOHA CR Concentration (g/m^3)	HABIT CR Concentration (g/m^3)
A	326	3.86	0.35
D	343	4.06	0.96
F	373	4.49	1.53

Finally, a sensitivity study of air temperature effects on the HABIT and ALOHA CR CO_2 concentration was also perform with this research. Table 3-9 shows the HABIT and ALOHA CO_2 concentration results for four air temperature (10, 20, 30, and 40 °C) data points. The HABIT CR CO_2 concentration results are the same (0.96 g/m^3) value for all four air temperature data points. Indicating that the air temperature has no effect on the maximum CR CO_2 concentration calculated by the HABIT code. However, the maximum atmospheric and CR CO_2 concentrations (360 g/m^3 and 4.26 g/m^3, respectively) calculated by the ALOHA code occurs at 10 °C. When the air temperature increases, the maximum atmospheric and CR CO_2 concentrations calculated by the ALOHA codes decreases. Finally, these sensitivity analyses of wind speed, atmospheric stability classification, and air temperature, indicate that the wind speed has the larger effect in the calculation of CR CO_2 concentration in both the HABIT and ALOHA codes.

Table 3-9 Sensitivity Study of Air Temperature for Maanshan NPP

Air temperature (°C)	ALOHA Atmospheric Centerline Downwind Concentration (g/m^3)	ALOHA CR Concentration (g/m^3)	HABIT CR Concentration (g/m^3)
10	360	4.26	0.96
20	353	4.17	0.96
30	343	4.06	0.96
40	336	3.97	0.96

In summary, the SNAP/RADTRAD and HABIT code results indicate that the CR habitability of Maanshan NPP can be maintained for the above cases.

4 CONCLUSIONS

The purpose of this research is to use the Maanshan NPP data from references [8] through [12], the SNAP/RADTRAD code, the HABIT code, and the ALOHA code to establish the analysis methodology for CR habitability. Based on current NRC for licensing review practices, the formal code used to perform the CR radiological dose assessment and the latter two codes used for toxic chemical in the air. This analysis methodology evaluated the Maanshan NPP CR habitability under the LOCA DBA and the liquid CO_2 storage tank burst scenarios. The main summary points are as follows:

- The SNAP/RADTRAD EAB and LPZ TEDE and thyroid doses are consistent with FSAR [8] data for the EAB and LPZ. Indicating that the SNAP/RADTRAD model of Maanshan NPP has a good accuracy.
- The SNAP/RADTRAD EAB and LPZ TEDE and thyroid doses are below the reactor siting criteria of 10 CFR Part 100 [4]. Additionally, SNAP/RADTRAD CR occupational doses are below the criteria in references [2] and [3].
- The results of HABIT CR CO_2 concentration is below the CO_2 toxicity concentration limit from Table 1 of RG 1.78 [7].
- The HABIT CR CO_2 concentration results are less than the ALOHA CR CO_2 concentration results. Additionally, the ALOHA CR CO_2 concentration results are also below the CO_2 toxicity limit from Table 1 of RG 1.78 [7].
- The sensitivity analyses of wind speed, atmospheric stability classification, and air temperature, indicate that the wind speed has the largest effect in the calculation of CR CO_2 concentration in both the HABIT and ALOHA codes.
- According to the SNAP/RADTRAD and HABIT code results, the CR habitability of Maanshan NPP can be maintained in both the LOCA DBA and the liquid CO_2 storage tank burst scenarios.
- Based on the above results and experiences, this analysis methodology as well as the associated computational codes can be applied to assess all other NPPs in Taiwan in the near future.

5 REFERENCES

[1] **NUREG/CR-7220**, “SNAP/RADTRAD 4.0: Description of Models and Methods,” U.S. Nuclear Regulatory Commission, Washington, DC, June 2016.

[2] **GDC-19**, General Design Criterion 19, “Control Room”, of Appendix A to the Code of Federal Regulations, Title 10, Energy, Part 50 (10 CFR Part 50), “Domestic Licensing of Production and Utilization Facilities.

[3] **NUREG-0800**, “Standard Review Plan,” (SRP) Chapter 6.4, “Control Room Habitability System,” Revision 3, U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

[4] **10 CFR Part 100**, Code of Federal Regulations, Title 10, Energy, Part 100, “Reactor Site Criteria.”

[5] **HABIT 2.0**, “User’s Guide (Draft),” U.S. Nuclear Regulatory Commission, Washington, DC, July 2016.

[6] **NOAA Technical Memorandum NOS OR&R 43**, “ALOHA® (Areal Locations of Hazardous Atmospheres) 5.4.4, Technical Documentation,” National Oceanic and Atmospheric Administration, Emergency Response Division, Seattle, WA, November 2013.

[7] **Regulatory Guide 1.78, Revision 1,** “Evaluating the Habitability of a Nuclear Power Plant Control Room during a Postulated Hazardous Chemical Release,” U.S. Nuclear Regulatory Commission, Washington, DC, December 2001.

[8] Taiwan Power Company, Maanshan Nuclear Power Station Final Safety Analysis Report (FSAR) (2013).

[9] **INER-7001**, “A Simplified Model for Radionuclide Transport and Removal and Dose Estimation,” Institute of Nuclear Energy Research, Atomic Energy Council of the Taiwan (ROC), Taoyuan, Taiwan, 2010.

[10] **INER-10594**, “The Radiological Dose Assessment of Loss-of-Coolant Design Basis Accident in Maanshan Final Safety Analysis Report Using RADTRAD,” Institute of Nuclear Energy Research, Atomic Energy Council of the Taiwan (ROC), Taoyuan, Taiwan, 2013.

[11] **INER-11555**, “Control Room Dose Analysis for Maanshan PWR Plant during Design Basis Loss of Coolant Accident,” Institute of Nuclear Energy Research, Atomic Energy Council of the Taiwan (ROC), Taoyuan, Taiwan, 2014.

[12] Taiwan Power Company, Maanshan Nuclear Power Station Training Materials, 2006.

[13] **TID-14844**, “Calculation of Distance Factors for Power and Test Reactor Sites,” U.S. Atomic Energy Commission, Washington, DC, March 1962.

[14] **NUREG-1465**, “Accident Source Terms for Light-Water Nuclear Power Plants,” U.S. Nuclear Regulatory Commission, Washington, DC, February 1995.

[15] Sun, Casper, “Introduction of HABIT v2.0 Computer Code,” RAMP Newsletter, Issue 4, Fall 2016, U.S. Nuclear Regulatory Commission, Washington, DC, October 2016.

[16] **Regulatory Guide 1.23, Revision 1**, “Meteorological Monitoring Programs for Nuclear Power Plants,” U.S. Nuclear Regulatory Commission, Washington, DC, March 2007.

NRC FORM 335 (12-2010) NRCMD 3.7 — U.S. NUCLEAR REGULATORY COMMISSION **BIBLIOGRAPHIC DATA SHEET** *(See instructions on the reverse)*	1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.) **NUREG/IA-0506**
2. TITLE AND SUBTITLE Using SNAP/RADTRAD and HABIT to Establish the Analysis Methodology for Maanshan Pressurized-Water Reactor (PWR)	3. DATE REPORT PUBLISHED MONTH: **January** YEAR: **2019** 4. FIN OR GRANT NUMBER
5. AUTHOR(S) Jong-Rong Wang, Yu Chiang, Wen-Sheng Hsu, Hsiung-Chih Chen, Jung-Hua Yang, Chun-Kuan Shih, Shao-Wen Chen, Ting-Yi Wang*, Tzu-Yao Yu*	6. TYPE OF REPORT Technical 7. PERIOD COVERED (Inclusive Dates)

8. PERFORMING ORGANIZATION - NAME AND ADDRESS (If NRC, provide Division, Office or Region, U. S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

Nuclear and New Energy Education and Research Foundation; Institute of Nuclear Engineering and Science,National Tsing Hua University 101 Section 2, Kuangfu Rd., Hsinchu, Taiwan

*Department of Nuclear Safety, Taiwan Power Company 242, Section 3, Roosevelt Rd., Zhongzheng District, Taipei, Taiwan

9. SPONSORING ORGANIZATION - NAME AND ADDRESS (If NRC, type "Same as above", if contractor, provide NRC Division, Office or Region, U. S. Nuclear Regulatory Commission, and mailing address.)

Division of Systems Analysis
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

10. SUPPLEMENTARY NOTES
S. Bush-Goddard, RAMP Project Manager, C. Sun, HABIT Project Manager, J. Tomon, SNAP/RADTRAD Project Manager

11. ABSTRACT (200 words or less)

The objective of this study is to evaluate the control room (CR) habitability for the pressurized-water reactor (PWR) at the Maanshan nuclear power plant (NPP) site. The study focuses on the analysis methodology for CR habitability using the Symbolic Nuclear Analysis Package/RADionuclide, Transport, Removal And Dose Estimation (SNAP/RADTRAD) and the HABITability (HABIT) computer codes and is performed in two parts. In the first part of the analysis, the SNAP/RADTRAD computer code is used to develop models to evaluate the occupational radiation doses in the CR and the cumulative radiation doses at the exclusion area boundary (EAB), and low population zone (LPZ) during a loss-of-coolant accident (LOCA) design-basis accident (DBA). In the second part of the analysis, the HABIT code is used to evaluate the CR habitability during an accidental release of liquid carbon dioxide (CO2) from a storage tank under burst conditions. Additionally during this step, the HABIT code results were compared with the results from the Areal Locations of Hazardous Atmospheres (ALOHA) computer code results.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)	13. AVAILABILITY STATEMENT
Computer Code, HABIT, SNAP/RADTRAD, ALOHA, Reactor Accidents, Design Basis Accidents (DBA), Loss-of-Coolant Accidents (LOCA), Control Room (CR), Low Population Zone (LPZ), Exclusion Area Boundary (EAB), National Tsing Hua University (NTHU), Pressurized-Water Reactor (PWR), Maanshan Nuclear Power Plant (MNPP)	unlimited 14. SECURITY CLASSIFICATION *(This Page)* unclassified *(This Report)* unclassified 15. NUMBER OF PAGES 16. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

OFFICIAL BUSINESS

NUREG/IA-0506 Using SNAP/RADTRAD and HABIT to Establish the Analysis Methodology for Maanshan PWR January 2019