August 8, 2011

MEMORANDUM TO: Kathy H. Gibson, Director
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Office of Nuclear Regulatory Research

FROM: Charles E. Ader, Director /**RA**/
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SUBJECT: USER-NEED REQUEST FOR THE OFFICE OF NUCLEAR REGULATORY RESEARCH TO IMPROVE AND BENCHMARK THE CONTROL ROOM HABITABILITY PACKAGE CODE AND ASSESS THE AREAL LOCATIONS OF HAZARDOUS ATMOSPHERES CODE FOR CONTROL ROOM HABITABILITY

This memorandum describes the Office of New Reactors (NRO) user need request for the Office of Nuclear Regulatory Research (RES) to (1) improve and benchmark the Control Room Habitability Package (HABIT) code for toxic gas evaluation for control room (CR) habitability; (2) assess the Areal Locations of Hazardous Atmospheres (ALOHA) code to develop insights into its use for toxic gas evaluations; and (3) provide recommendations for updating Revision 1 to Regulatory Guide 1.78. "Evaluating the Habitability of a Nuclear Power Plant Control Room during a Postulated Hazardous Chemical Release." The experience gained by the staff through the toxic gas reviews of several combined license (COL) applications has led to the current user need request. The overall goal of the proposed activity is to establish an appropriate and consistent confirmatory analysis framework for evaluating CR habitability in the event of a nearby toxic chemical release. During its development, the NRO staff has discussed this user need request with the members of the Health Effects Branch at the Division of Systems Analysis (RES/DSA/HEB). Steven Schaffer has been our point of contact at RES/DSA/HEB. NRO staff will continue to coordinate with RES and establish a mutually acceptable prioritization and schedule for these activities subject to available resources. NRO is expecting to review new design certifications and continue to review combined license applications in the FY13 timeframe and the availability of improved tools would greatly facilitate those reviews.

Background

Revision 1 to Regulatory Guide 1.78 endorses the use of HABIT, which is an integrated set of computer codes designed to evaluate CR habitability following a postulated release of toxic chemicals or radioactive materials [Refs. 1-3]. Given information about the design of a nuclear power plant, a scenario for the release of a toxic chemical, the physical properties of the toxic chemical, atmospheric transport and diffusion conditions, and the air flows and protective systems of the CR, HABIT can be used to estimate the CR personnel's exposure to the chemical.

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HABIT was developed by Pacific Northwest National Laboratory (PNNL) and is available to the public through the Oak Ridge National Laboratory's Radiation Safety Information Computational Center (RSICC). The original version of HABIT, Version 1.0 (HABIT V1.0), was introduced in 1996 [Ref. 1]. The latest version of HABIT, Version 1.1 (HABIT V1.1) was issued two years later in 1998 [Ref. 2] HABIT uses two modules, EXTRAN and CHEM, to perform CR toxic chemical evaluations. EXTRAN estimates short-term concentrations of a released hazardous material at a specified single location downwind (such as a CR air intake) by estimating the mass entering the atmosphere and then transporting and dispersing the resulting plume downwind. EXTRAN computes the atmospheric concentration history at the CR air intake from the time the airborne chemical first arrives there. Using the transient toxic chemical concentration at the CR intake predicted by EXTRAN and the CR volume and outdoor air flow intake information, CHEM calculates the transient chemical concentration inside the CR by balancing the inflow of the toxic outdoor air with the outflow of the mixed CR air. CHEM assumes that toxic chemicals are not removed by filters, settling, or chemical reaction. CHEM can also account for any bottled fresh air in the CR.

Several COL applicants have performed their CR toxic gas evaluations using ALOHA [Ref. 4]. ALOHA is a public domain computer code that was jointly developed by the United States Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) for the purpose of estimating threat zones associated with hazardous chemical releases, including toxic gas clouds, fires, and explosions. The staff has recognized the need to comprehensively assess ALOHA vis-à-vis HABIT to develop insights into the use of ALOHA for toxic gas evaluations.

Based on the technical reviews of several COL applications and the interaction with contractors over the last couple of years, NRO has concluded that the toxic chemical portion of HABIT would benefit from improvements to become a more useful tool for the staff in performing confirmatory CR habitability toxic gas analyses. NRO has formulated this user need request to RES which includes tasks to improve and benchmark the HABIT code for toxic gas evaluation for CR habitability; and to assess ALOHA to develop insights into its use for toxic gas evaluations.

<u>Improve and Benchmark the HABIT Code for Toxic Gas Evaluation</u>

Task 1: Permanently implement the EXTRAN simulation time extension

In 2009, RES supported NRO by providing a provisional modification to HABIT V1.1 which enabled longer simulation runs needed to support the review of several COL applications. The HABIT V1.1 code simulates CR toxic gas exposure duration with default limits of either 7.5 minutes or 22.5 minutes, depending upon the separation distance between the CR intake and the chemical source. The NRO staff had noticed in using HABIT V1.1 for its CR habitability reviews of COL applications that in some cases the toxic gas concentrations inside and outside the CR continued to rise at the end of the simulation. RES subsequently assisted NRO by modifying EXTRAN to run for longer durations to address the question whether the toxic gas concentration inside the CR would exceed its Immediately Dangerous to Life and Health (IDLH) value past 22.5 minutes. The EXTRAN code as modified by RES extended the previous default limits of 7.5 minutes and 22.5 minutes to 22.5 minutes and 124 minutes, respectively. However, NRO has later found that the extension of the 7.5 minute runs to 22.5 minutes is still not sufficient. Therefore, the extension of the exposure duration limits should be implemented in HABIT in a more robust manner, which will require better understanding of the variables and algorithm coded across several Fortran subroutines.

Task 2: Add more chemicals to HABIT

The chemical and physical properties of approximately two dozen chemicals are currently available within HABIT. The user has to specify properties for other chemicals. NRO would benefit if the HABIT code is modified to add some more frequently encountered chemicals, such as gasoline, n-heptane, n-hexene, 1-hexene, ethylene, nitrogen, acetic acid, hydrochloric acid, and sodium hypochlorite. Other chemicals deemed important but not included in this list should also be identified and added in consultation with NRO. For the chemicals that are mixtures of other compounds, such as gasoline, conservative surrogates need to be established for toxic gas evaluation purposes. Revision 1 to Regulatory Guide 1.78, Table 1 would also need to be updated to include the toxicity limits of the additional chemicals.

Task 3: Assess and implement a heavy-gas dispersion model within HABIT

ALOHA offers both heavy and neutral-density dispersion models. For its confirmatory calculations for some COL reviews, the staff has used the HABIT code which only has a neutral-density model. The Advisory Committee on Reactor Safeguards (ACRS) observed in its February 17, 2011, report on the safety aspects of the V.C. Summer COL application (ML110450490), that HABIT only models neutral density gas dispersion and does not consider heavy gas effects. As HABIT does not offer an explicit heavy gas dispersion model as ALOHA does, the heavy gas dispersion capabilities of HABIT and ALOHA shall be investigated vis-à-vis pertinent experimental data. Implementing a heavy-gas dispersion model within HABIT and validating it against experimental data are desired, if feasible.

Task 4: Investigate the sensitivity of HABIT results to the "Intake Height" input parameter

Some NRO reviewers have noticed that the HABIT concentration results are sensitive to the CR outdoor air "intake height", which is an input parameter specified by the user. HABIT's predicted concentrations are maximum at the ground level, and drop rapidly with altitude. If the specified CR intake height is high enough, the resulting concentrations at the CR intake and, thus, inside the CR, may be quite low. This "intake height effect" should be investigated and compared with available experimental data to ascertain whether it is (1) physically realistic, (2) a Gaussian dispersion model artifice, or (3) an error in the HABIT code. Addressing the "intake height effect" is especially important, as some COL applicants have submitted CR habitability analyses that take credit for high CR intake elevations. Comparing the "intake height effect" as predicted by HABIT and ALOHA for a range of atmospheric conditions and chemicals should be included as it may also lead to additional insights.

Task 5: Verify and validate the updated HABIT code against the standard HABIT QA examples

The updated HABIT code resulting from the above activities should be benchmarked against the standard examples already documented in the HABIT documentation package. The NRO staff foresees the following three verification and validation activities.

(1) Update the standard toxic chemical release examples for HABIT V1.1

NRO has been contacted by an industry consultant who attempted to test the HABIT V1.1 code [Ref. 2] against the standard toxic chemical release example (DEMO1) provided in the

HABIT V1.0 code documentation package [Ref. 1]. The industry consultant was unable to reproduce the standard example results. The discrepancy may have been caused by the fact that the standard toxic chemical release example presented in Reference 1 was developed using output generated by HABIT V1.0 whereas HABIT V1.1 contains a revised EXTRAN code. This should be investigated. If the standard toxic chemical release examples documented in Reference 1 are no longer applicable to HABIT V1.1, new standard examples shall be developed and documented for HABIT V1.1.

(2) Verify the HABIT code after it is modified

A quality assurance process should verify that the CR concentrations predicted by the HABIT V1.1 code modified to extend the toxic gas exposure durations of 7.5 minutes and 22.5 minutes, are the same as predicted by the original HABIT V1.1 code [Ref. 2], and the transition to the extended exposure durations is smooth.

(3) Validate the modified HABIT code against experimental data

In a letter report documenting its review of proposed Revision 1 to Regulatory Guide 1.78, dated September 16, 1999, (ML993620146), the ACRS stated “the staff should document evidence of the validity and the capability of computer codes endorsed in regulatory guides such as the HABIT code.” A staff response to the ACRS on October 29, 1999, (ML003691749) emphasized that relevant physical models in the HABIT code were peer reviewed and validated against experimental data. Revision 1 to Regulatory Guide 1.78 was issued in December 2001. Validating the modified HABIT code against more recent data could prove to be more insightful. A literature survey may be warranted for this purpose.

Task 6: Provide a Graphical User Interface (GUI) for HABIT

HABIT V1.1 user interface and input/output file management are still based on the DOS environment, which is not efficient. A Windows based Graphical User Interface (GUI) for HABIT would be highly desirable, if the required development resources are comparable with that of the other tasks in the current user need request.

Task 7: Implement Automatic Parametric Studies for HABIT

The development team should look into whether HABIT code could be restructured to run sensitivity studies for a toxic chemical release for various meteorological parameters, such as, wind speed, atmospheric stability class, and air temperature. The automation of parametric studies in HABIT will significantly increase the efficiency of the toxic gas evaluation for CR habitability.

Develop Insights into the Use of ALOHA for Toxic Gas Evaluations

Task 1: Investigate the potential over-prediction by ALOHA in some cases

While using ALOHA to analyze the toxic gas threat to the CR, NRO has observed that ALOHA sometimes predicts higher toxic gas concentrations inside and outside the CR (by orders of magnitude in some cases) as compared to HABIT. Occasionally, ALOHA predictions of outdoor toxic gas concentration at the intake of the CR significantly exceeded one million ppm (parts per million) ---- the theoretically possible upper limit for any substance. The overall mass balance in ALOHA on the released gas plume during atmospheric dispersion may be suspect.

This may suggest a possible weakness in ALOHA that needs to be assessed for accepting ALOHA analyses as technical basis for regulatory findings regarding CR habitability under a toxic gas threat.

Task 2: Establish whether ALOHA's fixed liquid puddle size is appropriate

The toxic gas concentrations inside the CR are sensitive to the size of the liquid puddle resulting from a chemical release. As the puddle size increases, the surface area of the puddle becomes larger, thereby increasing the rate of liquid evaporation that results into higher gas concentrations inside the CR. HABIT models the puddle area as expanding under the influence of gravity and eventually contracting due to evaporation. ALOHA does not model the size of the liquid puddle. Instead, puddle size is a user-specified input parameter in ALOHA, which is not allowed to exceed a diameter of 200 meters (or an area of 31,400 square meters).

The CR concentration can exceed the IDLH level for large puddle sizes that exceed the ALOHA limit of 200 meters. For a sufficiently large liquid chemical spill, the puddle diameter may grow beyond 200 meters, unless it is contained within a smaller area surrounded by natural or constructed boundaries. This aspect of HABIT vs. ALOHA shall be investigated and conclusions should be drawn regarding an appropriate approach for handling puddle size.

Task 3: Establish whether ALOHA's 60-minute simulation limit is appropriate

As discussed previously, the staff identified a need to extend the HABIT plume exposure duration beyond the code's current default limits of 7.5 minutes and 22.5 minutes. ALOHA has a similar simulation limit of 60 minutes. Some ALOHA runs show that the toxic gas concentrations inside and outside the CR are still rising when the simulation automatically stops at 60 minutes. Complimentary HABIT runs have shown that, in some cases, CR concentrations can exceed the IDLH exposure level past the first hour. The NRC cannot modify the ALOHA code's 60-minute simulation limit because the NRC does not have access to the ALOHA source code. NRO sees a need to establish whether ALOHA's 60-minute simulation limit is conservative enough to meet NRC's rules and regulations. The staff is not aware of any regulatory guidance regarding the length of toxic gas release simulation time.

Task 4: Understand why ALOHA does not require some important thermo-physical properties necessary to model liquid evaporation

ALOHA has a large database of chemicals and the user can also add more chemicals to the ALOHA database. NRO has noticed that the ALOHA chemicals database does not include some fundamental thermo-physical properties, such as latent heat of vaporization and liquid density or specific gravity. HABIT uses these properties to determine the liquid puddle size and evaporation rate, both of which influence the CR concentrations.
The goal of this task is to ascertain whether the absence of these chemical properties from the ALOHA model suggests any significant weakness in ALOHA or sheds any light on the intended use of ALOHA.

Task 5: Compare ALOHA and HABIT results for a range of chemical release scenarios, atmospheric conditions, and CR design

This activity should be undertaken only when all of the above concerns for ALOHA have been duly resolved, and only if ALOHA is still considered a credible alternate to HABIT. By systematically comparing ALOHA and HABIT results for a range of chemical release scenarios, atmospheric conditions, and CR designs, consistent patterns of weaknesses and strengths in the two codes may be identified. Comparing HABIT and ALOHA results against any experimental data will be highly desirable as well.

Provide recommendations for an update to Regulatory Guide 1.78

The activities proposed in this user need request can potentially lead to regulatory insights into the use of HABIT and ALOHA for CR toxic gas evaluation that would require updating Regulatory Guide 1.78. Provide recommendations for updating Regulatory Guide 1.78, if any.

References

[1] *Computer Codes for Evaluation of Control Room Habitability (HABIT)*, NUREG/CR-6210, PNNL-10496, June 1996.

[2] *Computer Codes for Evaluation of Control Room Habitability (HABIT V1.1)*, NUREG/CR-6210, Supp.1, PNNL-10496, October 1998.

[3] *EXTRAN: A Computer Code for Estimating Concentrations of Toxic Substances at Control Room Air Intakes,* NUREG/CR-5656, PNL-7510, 1A, 1B, March 1991.

[4] *ALOHA User's Manual*, U.S. EPA, NOAA, February 2007.

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References

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[2] *Computer Codes for Evaluation of Control Room Habitability (HABIT V1.1)*, NUREG/CR-6210, Supp.1, PNNL-10496, October 1998.

[3] *EXTRAN: A Computer Code for Estimating Concentrations of Toxic Substances at Control Room Air Intakes,* NUREG/CR-5656, PNL-7510, 1A, 1B, March 1991.

[4] *ALOHA User's Manual*, U.S. EPA, NOAA, February 2007.

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