The NRC Human Reliability Analysis Research Program

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Abstract

The U.S. Nuclear Regulatory Commission's (NRC's) Human Reliability Analysis (HRA) Research Program is aimed at: (1) developing improved HRA methods, tools, and data; (2) developing HRA results and insights; and (3) providing HRA support to other NRC programs. The Fiscal Year 2001-2005 technical tasks include the development of improved methods and data for HRA quantification, the performance of a number of technical analyses supporting probabilistic risk assessment studies of various engineering issues (e.g., pressurized thermal shock risk), the development of improved methods for specific HRA problems (e.g., the treatment of latent errors), and the development of HRA guidance for a variety of user audiences. A program plan has been developed to support the execution of the research program. This paper summarizes that program plan.

1. Background

As stated in the U.S. Nuclear Regulatory Commission's (NRC's) policy statement on the use of probabilistic risk assessment (PRA) [1], the NRC intends to increase the use of PRA technology in "all regulatory matters to the extent supported by the state of the art in PRA methods and data." Some of the ongoing regulatory activities potentially affected include efforts to make Part 50 of the Code of Federal Regulations more risk-informed [2];[1] the updating of the general risk-informed framework for supporting licensee requests for changes to a plant's licensing basis, described in a revised version of Regulatory Guide (RG) 1.174 [4]; the revision of the reactor oversight process to incorporate risk information [5]; and the evaluation of the significance of operational events [6].

Human reliability analysis (HRA), a process for identifying potentially important human failure events (HFEs) and assessing their likelihood, is an essential component of PRA.[2] Previous analyses and past experience from operational events show that credible HFEs can usually be identified for most (if not all) of the safety

[1] As stated in Ref. 3, risk-informed regulation is "an approach to regulatory decision making that uses risk insights as well as traditional considerations to focus regulatory and licensee attention on design and operational issues commensurate with their importance to health and safety."

[2] In this paper, the term "human failure event" is used instead of the more generic "human error" to avoid an implication of blame (e.g., for situations where operators follow their training, but the training is inappropriate for the situation) and to provide an explicit tie with the PRA.

functions treated in PRAs. It is therefore not surprising that HRA generally plays an important role in PRA (see, for example, a review of the results of Individual Plant Examinations [7]), and that uncertainties in HRA results are often an important driver in the uncertainty in the overall results of the PRA. Given the increasingly important role of PRA in regulatory decision making, therefore, it is important to have HRA methods, tools, and data that can, for a given risk-informed decision, adequately assess the human contribution to risk. These methods, tools, and data need to support the identification of potentially significant HFEs and the quantification of the likelihood of these HFEs. The quantification process should appropriately address dependencies of the HFEs on the scenario (including other HFEs in the scenario) and the uncertainties in the probabilities of the HFEs. Depending on the needs of the particular decision, the analysis may need to be performed at a sufficient level of detail to support the identification of key causes of error and their potential fixes.

Due to the importance of HRA, and to the uncertainties in the results of HRA (which have been recognized since the early days of PRA), the NRC has, over the years, conducted a number of HRA research and development activities. For example, NRC has supported the development of the well-known THERP [8] and SLIM-MAUD [9] methods, as well as more exploratory methods for assessing the impact of organizational factors on risk [10]. The NRC has also supported the development of the Simplified Plant Analysis Risk (SPAR) HRA method [11], which is being used in a number of regulatory applications.

NRC's recent HRA research and development efforts have focused on the development of A Technique for Human Event Analysis (ATHEANA) [12]. ATHEANA is an HRA method aimed at addressing the issue of scenario-specific context and a particularly challenging topic in HRA: the treatment of errors of commission. ATHEANA's underlying premise is that significant human errors occur as a result of a combination of influences associated with plant conditions and specific human-centered factors that trigger error mechanisms in the plant personnel. This premise is based on the work of researchers investigating the causes of human error and is supported by reviews of operational events. It requires the identification of these combinations of influences, called the "error-forcing contexts" (EFCs), and the assessment of their influence.

The efforts of the ATHEANA team have led to a method sufficiently developed for use (as one tool in the HRA toolbox) in actual regulatory applications (e.g., the analysis of pressurized thermal shock scenarios in support of a potential change to 10 CFR 50.61 [13]). Recognizing this state of development, and that the NRC has a broad range of HRA research and application needs (beyond ATHEANA) which need to be addressed, the NRC staff has developed an HRA Research Program Plan to guide its efforts in the next few years.

The plan includes research and development tasks (to develop improved HRA methods and tools in selected areas) and HRA applications tasks (to support ongoing risk-informed decision making activities). It builds on the results of past HRA research (both conducted at NRC and other organizations), and includes joint data collection and analysis activities with the NRC Program on Human Performance in Nuclear Power Plant Safety (PHP) [14], and collaboration activities with various international research groups. It also includes tasks aimed at ensuring that the HRA Research Program effectively communicates its results to users and other interested stakeholders.

This paper summarizes the HRA Research Program Plan. The plan is aimed at addressing key technical issues in HRA identified by the staff and by the Advisory Committee on Reactor Safeguards (ACRS) in its reviews of NRC's HRA activities [15-16]. Additional details can be found in the full report documenting the plan [17].

2. Program Objectives

The overall purpose of the HRA research program is to support the NRC's Risk-Informed Regulation Implementation Plan (RIRIP) [18], which has been developed to implement the NRC's strategic plan, especially with respect to a number of the performance goals in the Nuclear Reactor Safety and Nuclear Materials Safety strategic arenas [19]. The general objectives of the program are as follows.

- Develop improved HRA methods, tools (including guidance), and data needed to support NRC regulatory activities, including the broad implementation of risk-informed regulation.
- Develop HRA results and insights to support the development of technical bases for addressing identified or potential safety issues.
- Provide HRA support for the planning and execution of NRC programs and activities (e.g., the PHP) outside the immediate scope of the RIRIP.
- Ensure effective communication of research results to end users.
- Ensure effective use of resources in satisfying the preceding objectives.

The specific tasks planned for FY 2001-2005, and their associated technical objectives, are listed in Section 3 of this paper. Key milestones are identified in Section 4, and potential longer-term activities (post-FY 2005) are discussed in Section 5.

3. Task Descriptions

The HRA research program tasks for FY 2001-2005 are listed in Table 1. The tasks and their associated technical objectives are discussed in this section. These tasks are intended to support the achievement of the overall program objectives listed in Section 2; they have been selected based upon a consideration of current and anticipated reactor safety and materials safety staff needs, on HRA research results developed by NRC and others (especially with respect to the treatment of context in accident scenario analysis), and on the recognition that NRC's risk-informed regulatory needs are likely to require a variety of HRA tools (including guidance as well as analysis methods). As indicated in Section 1, the tasks represent a significant broadening of activities beyond the NRC's recent HRA research work (which concentrated on developing ATHEANA).

Some of the tasks listed in Table 1 need to be repeated (or performed nearly continuously), while others will only need to be performed once. The former are considered support tasks and are indicated by letters; the latter are one-time technical tasks and are indicated by numbers. Table 2 provides a mapping between the tasks and the program objectives. Note that most of the tasks support multiple objectives.

The following sections provide, for each task, the task objectives and a brief description of the technical approach. Milestone information is provided in Section 4.

Table 1. NRC HRA Research Program Tasks, FY 2001-2005

Task	Title
1	HRA Data Collection and Analysis
2	HRA Guidance Development
3	HRA Quantification and Uncertainty
4	Pressurized Thermal Shock HRA
5	Fire HRA
6	Steam Generator Tube Rupture HRA
7	HRA for Aging Cable Systems
8	HRA for Materials and Waste Applications
9	Reactor Systems Synergisms and HRA
10	HRA for Upgraded and Advanced Control Rooms
11	Latent Errors in HRA
12	HRA Extended Applications
13	Formalized Methods: Screening, Individual and Crew Modeling
A	HRA Research Planning
B	HRA Results Communication
C	General NRC HRA Technical Support
D	Industry and International HRA Activities

Table 2. HRA Research Program Objectives and Supporting Tasks

Objective	Supporting Tasks
Develop improved HRA methods, tools (including guidance), and data needed to support NRC regulatory activities, including the broad implementation of risk-informed regulation	1-13, D
Develop HRA results and insights to support the development of technical bases for addressing identified or potential safety issues	4-10
Provide HRA support for the planning and execution of NRC programs and activities (e.g., the PHP) outside the immediate scope of the RIRIP	1, 11, C
Ensure effective communication of research results to end users	B, D
Ensure effective use of resources in satisfying the preceding objectives	A

3.1. Task 1 – HRA Data Collection and Analysis

One of the common criticisms of the current HRA state of the art concerns the strength of the available data. Data are needed not only for the quantification of human failure event (HFE) probabilities, but also to support the HRA models (which, for example, postulate that certain factors are part of the error forcing context - EFC, and that there are specific relationships between the EFC elements and the HFE probability).

Regarding HFE quantification, it should be noted that ATHEANA, like other advanced HRA methods, distinguishes between the occurrence of a particular EFC, and the occurrence of an unsafe act (UA), given the EFC. Thus, data are needed to assess both the likelihood of an EFC (given the PRA scenario in which the HFE is embedded), and the conditional likelihood of a UA (or set of UAs) leading to the HFE, given the EFC. However, in general, the information available from reports on operational events is not of sufficient quality to directly address these two issues. Furthermore, the risk significant HFEs for which probabilities are desired are typically events in accident scenarios that have not yet been observed. In these cases, classical statistical methods cannot be used to develop the HFE probabilities. It can be seen that the use of subjective judgment is unavoidable, and that the Bayesian framework for estimation, which directly addresses situations where data are sparse, provides an appropriate way to proceed.

This is an important point from the standpoint of a data collection program, because the Bayesian framework accommodates different forms of "evidence," including indirect observations, model predictions, and expert judgment, as well as actuarial data. The precise formalisms for employing these data in an HRA context are not yet developed (see Task 3). However, regardless of how the formalisms are developed, it is important to recognize that a wide variety of information can be used in a Bayesian analysis. Therefore, the data collection activity need not focus on one particular source of information (e.g., operational events, simulator experiments, operator requalification tests) over another.

It is also important to recognize that the quantity and quality of HRA data has been a concern since the time of the landmark Reactor Safety Study [20] (see, for example [21]), and that this concern is not expected to be resolved quickly (given the issues mentioned above). Therefore, it can be expected that substantial improvements will require a sustained, long-term, and potentially resource-intensive effort.

The objectives of this task are to:

- define the qualitative and quantitative data needs of HRA;
- develop long-term working relationships with key HRA and human factors research programs capable of generating new data; and
- collect and analyze data to support HRA model development and quantification.

This task is to be performed as a joint activity with the NRC's PHP [14][3]. This will increase the degree of human factors input on the phenomenological issues being addressed and will support the development of a strong connection with ongoing experimental research programs.

The first step in the task is to define the data needs for HRA, and especially HRA quantification. This requires strong interactions with Task 3 ("HRA Quantification and Uncertainty"). Activities will be performed to: identify potential cooperating programs in addition to those with which NRC already has cooperative

[3] Recently, staff has decided to merge human factors work in the PHP into the HRA Research Plan.

agreements, communicate these needs to cooperating programs, analyze existing data from these programs, specify additional data collection/generation activities, and analyze the data from these additional activities.

In parallel with these activities, which are largely focused on experimental programs, efforts will be made to collect information from programs compiling human-related operational experience data and related sources. Regarding the latter, efforts will be made to collect information on the technical bases supporting the industry's current symptom-based emergency operating procedures. This information is likely to include the scenario variations considered by the procedure developers, and the bases for addressing or not addressing these variations in the procedures.

Products from this task include an initial evaluation of HRA data needs, a complete evaluation of a selected set of simulator data, and a complete evaluation of symptom-based procedures data.

3.2. <u>HRA Guidance Development</u>

As indicated earlier in this paper, most of the recent NRC HRA research work has focused on the development of improved HRA methods (especially ATHEANA). While these improved methods are proving useful in some risk-informed applications, it is recognized that not all risk informed applications require such detailed analyses. A key question that must be faced by both HRA analysts and HRA reviewers is under what conditions are the improved methods needed, and under what conditions are the older (and widely used) methods sufficient. Another question is how can the selected method best be applied to the problem at hand.

The objectives of this task are to:

- develop lessons learned from past HRA research activities to support risk-informed regulatory applications; and
- develop guidance for HRA analysts and reviewers to support risk-informed regulatory applications.

The first step under this task will be to develop lessons learned from recent HRA research activities (including the ATHEANA development process) to support ongoing and anticipated risk-informed regulatory applications. This is expected to involve: a) an assessment of the type, quality, and characteristics of HRA information needed to support such regulatory applications; b) a review and evaluation of a selected number of "first generation" HRA methods (e.g., THERP, ASP HRA, HCR/ORE, SLIM-MAUD) from the perspective of these information needs; c) the characterization of the information provided by recent HRA research relative to the needs and gaps identified by the preceding two activities; and d) the identification of gaps remaining to be addressed.

The second step will be to develop guidance for performing and reviewing HRA analyses in support of risk-informed regulatory applications. This work will extend the results of the lessons learned activity above. It will also employ the results of ATHEANA applications completed under other tasks in the HRA research program (e.g., see Tasks 4-7). Initial guidance will be developed in FY 2002. It is anticipated that this guidance will be periodically updated as additional results from the HRA research program are developed.

The products from this task will be an HRA lessons-learned report and initial guidance for HRA performance and review to support risk-informed regulatory applications.

3.3. Task 3 - HRA Quantification and Uncertainty

In its 1999 review of ATHEANA as documented in NUREG-1624 Rev. 1 [12], the ACRS commented that the quantitative portion of the ATHEANA methodology “still needs significant development” [15]. One of the issues raised by the ACRS concerned whether the ATHEANA process for using expert judgment builds upon the body of work that has been developed on expert elicitation and the utilization of expert opinions (e.g., see NUREG/CR-6372 [22]).
A second, and somewhat related issue has been identified during the course of the PTS HRA. In the PTS analysis, as indicated in Section 3.4, efforts are being made to distinguish between aleatory (sometimes called “random”) and epistemic (sometimes called “state of knowledge”) uncertainties. To make this distinction, the meaning of the model parameters has to be clear. For example, in the case of HRA, the question is if the HFE probability, which is taken to be a measure of aleatory uncertainty, includes such things as variations in time of day at which the accident initiator occurs, or if these variations are to be included in the uncertainty about the HFE probability. It is not clear that the issue has been seriously addressed in the HRA literature. This is an important point because, when eliciting expert judgments, it is necessary to be clear and consistent about the quantity being estimated.

A third quantification issue follows from the discussion in Section 3.1: the information available to support quantification may be in a variety of forms (e.g., operational events, model predictions, results of simulator experiments, expert judgments, tabulated generic error probabilities). It is widely recognized that Bayes’ Theorem provides an appropriate formalism for dealing with these different forms of evidence. However, the specific implementations of Bayes’ Theorem to address certain forms of evidence have not been developed.

Based upon these three observations, it is apparent that work is needed on the fundamental issue of HFE quantification (which includes the treatment of uncertainties). This task is aimed at establishing an approach for dealing with the problem; it will lay the groundwork for the data collection activities pursued under Task 1.

The objective of this task is to develop and perform some preliminary tests of a formal approach to HFE quantification which:

- addresses uncertainties in a manner consistent with the PTS PRA philosophy [23];
- makes appropriate use of the various forms of available information; and
- appropriately accounts for potential biases in situations involving expert elicitation.

The first step in the task will be to develop an updated framework for HRA quantification. It is anticipated that this framework will draw explicit relationships between EFCs, UAs, and HFEs; will explicitly identify the contextual elements that need to be addressed as part of a given EFC; will explicitly categorize uncertainties in the various contextual elements as being aleatory or epistemic; will identify and categorize uncertainties in the estimation of the conditional probability of a UA (or set of UAs), given a particular EFC; and will indicate the general quantification process to be followed.

If a formal Bayesian approach is to be used, the second step will be to characterize the forms of evidence likely to be available to support quantification, and to develop appropriate likelihood functions for use in a Bayesian estimation process.

The third step, which can be conducted in parallel with the second step, will be to review relevant literature on elicitation processes, considering the quantification needs identified by the quantification framework, and then to adopt (or adapt) a process suitable for use in future HRA analyses.

The fourth step will be to combine the results of the preceding steps into a unified quantification process, to test this process through a demonstration problem and update as needed, and to develop recommendations for additional research.

Task 3 products include a framework for HRA quantification, a WGRISK presentation on the proposed process, and a finalized HRA quantification process.

3.4. Task 4 - Pressurized Thermal Shock HRA

As indicated in Ref. 13, NRC is currently developing the technical basis for modifying the Pressurized Thermal Shock (PTS) screening criteria specified in title 10 Part 50.61 of the U. S. Code of Federal Regulations. As part of this effort a probabilistic analysis of the risk posed by PTS in U. S. pressurized water reactors (PWRs) is being performed. The objective of this task is to provide HRA support to the PTS effort.

This task involves the application of ATHEANA towards the analysis of two pressurized water reactors (PWRs) - Oconee 1 and Beaver Valley 1, and the review of licensee-performed PRAs for two additional PWRs - Palisades and Calvert Cliffs 1. The ATHEANA application includes the development of a generic PTS functional event tree, the identification of potential HFEs, visits to the plant to talk with plant operators and trainers, modeling of the HFEs, and quantification of the HFEs. Consistent with the rest of the PTS PRA, the quantification process accounts for aleatory and epistemic uncertainties. (See Apostolakis [24-25] for the treatment of uncertainty in PRAs; Ref. 23 is a white paper on the treatment of uncertainty in the PTS effort.)

Products in this task will take the form of HRA input for the four plants, a report on the HRA approach and analyses, and input to the overall PTS technical basis report.

3.5. Task 5 - Fire HRA

Current fire PRA treatment of the response of plant operations staff to fire events is relatively crude. Some fire PRAs increase human error probabilities to account for the additional “stress” induced by the fire and some do not take credit for ex-main control room actions in the affected fire area (due to heat and smoke). However, these adjustments may not adequately address such plant-specific issues as the complexity of fire response procedures or the role of fire brigade members in accident response nor are they universally agreed upon. Moreover, they are quite judgmental; there currently is no strong technical basis for the magnitude (or even direction) of the adjustments.

Another concern is that certain elements of context that may arise due to the effects of fire (e.g., fire-induced faulty instrumentation readings, spurious equipment actuations, progressive loss of equipment over time) on operator situation assessment and decision making are not included, nor do they address incorrect operator actions stemming from incorrect decisions.

In principle, ATHEANA provides an appropriate approach for addressing these issues of task allocation, procedure complexity, and fire-induced EFCs. This task involves an application of ATHEANA to a number of plants. This application will support the “fire risk requantification study” to be performed under the fire risk research program [26]. It is expected that this application will be valuable to the area of fire PRA, as well as a useful and demanding test of ATHEANA.

The objective of this task is to support the fire risk requantification study through:

- investigating the possibility of developing an improved technical basis for incorporating fire-induced environmental effects in HRA;
- developing any necessary HRA methods for addressing EFCs associated with fire effects (e.g., environmental effects, loss of instrumentation, spurious actuations, time-dependent equipment losses);
- applying the fire HRA approach towards the analysis of the plants included in the requantification study;
- developing insights regarding the risk associated with the impact of fires and fire-induced failures on operator situation assessment, decision making, and associated actions; and
- developing insights regarding fire HRA methods.

This task will be performed in two steps. The first step represents a preparation for the requantification study. The preparations will include a review of the fire safety literature for information on environmental effects, a review of the need for improved HRA methods (if any) to account for other fire-induced EFCs, and the development and implementation of these modifications. This step will build upon the work underlying the preliminary ATHEANA application to fire reviewed by the ACRS, and upon the results of a review performed for the Individual Plant Examination of External Events (IPEEE) program [27].

The second step involves the application of the HRA approach to plants selected for analysis as part of the requantification study. As indicated in the Fire Risk Research Program Plan [26], the requantification study will require close cooperation between NRC and industry. It is hoped that the fire PRAs to be updated will represent a range of plant, plant ages, and FRA types (e.g., vulnerability analyses vs. detailed fire PRAs). The potential for applying the updated fire PRAs to evaluate specific issues at a plant will also be a consideration in the selection of plants to be analyzed. The precise plants to be analyzed will be determined following ongoing discussions with the industry regarding the extent and form of cooperation.

The initial product of this task will be completing the HRA preparation for the fire risk requantification study.

3.6. Task 6 - Steam Generator Tube Rupture HRA

In FY 2000, the Office of Nuclear Reactor Regulation (NRR) requested that the Office of Nuclear Regulatory Research (RES) perform a number of confirmatory research activities addressing steam generator tube integrity during postulated severe accidents in PWRs [28]. One of the desired outcomes is an "improvement of probabilistic safety assessment modeling of [severe accident-induced steam generator tube rupture (SGTR)] scenarios, including the effects of operator actions." This task will support a broader PRA effort addressing this user need. The objective of this task is to develop an improved HRA approach for post-severe accident SGTR scenarios.

The overall approach used will be similar to that used for the PTS project being supported by Task 4; it will involve an integrated engineering analysis of the scenario with inputs from PRA, thermal hydraulics, and structural analysis teams. The PRA portion of the analysis will build upon the accident progression event trees developed in an earlier study [29]. The HRA analysis is expected to employ the ATHEANA method to determine if all potentially significant HFEs have been identified, to identify significant EFCs, and to quantify the likelihood of the HFEs.

Because this task will be initiated in FY 2002, products will defined at that time.

3.7. Task 7 - HRA for Aging Cable Systems

Recent RES-sponsored environmental qualification tests involving the exposure of thermally aged and irradiated I&C cables to harsh environments (e.g., those caused by large loss of coolant accidents) have shown that certain cable types can fail and others can experience performance anomalies under design basis accident conditions[4] [30]. It can be inferred that the conditional failure probability of these cables (given the environment) may be sufficiently high to warrant their explicit treatment in PRAs. (Note that current PRAs assume that the cables are sufficiently reliable that they need not be modeled, except in the case of fire risk assessments.) Such a treatment would need to address, among other things, the possibility of spurious indications and actuations (as well as loss of function) and the consequent effect on the plant operators.

In FY-2002, RES will initiate an activity to evaluate the risk associated with cable system aging and failure [31]. This activity is currently expected to address the frequency-magnitude relationship for the post-accident environment for various initiators, variability in the aging of actual cables, cable fragilities, cable function and separation, and operator response to cable failures. The objective of this task (Task 7) is to provide HRA support to the NRC's aged cable risk assessment activity. Note that Task 9 (see Section 3.9) will address more general aspects of aging.

The plan for the aged cable risk assessment is under development. The approach used in this task will be developed to be consistent in scope and detail with the overall risk assessment. It is currently expected that the ATHEANA approach will be useful, as its focus on scenario context provides a means to address the potential confusion arising from the various cable failures that can occur. It is also expected that the HRA will require a review of events in which operators had to deal with significant losses of instrumentation (e.g., the Rancho Seco "light bulb" incident in 1978).

Because this task will be initiated in FY 2002, products will defined at that time.

3.8. Task 8 - HRA for Materials and Waste Applications

As indicated in the RIRIP [18], NMSS is currently developing a risk-informed regulation framework to cover applications involving the NRC's nuclear materials safety and nuclear waste safety arenas. This development activity involves, among other things, the performance of case studies on specific topics.

In 1997, NMSS requested assistance from RES in the development and implementation of a PRA of dry cask storage facilities [32]. The user need has since evolved into a request involving PRA and probabilistic fracture mechanics [33]. An important part of the PRA is the reliability of the loading, sealing, and onsite transportation of the casks. Therefore, the project requires the identification, analysis, and quantification of human error probabilities.

[4] Research results and industry inputs will be factored into the resolution of Generic Safety Issue GSI-168 on the Environmental Qualification of Low-Voltage Instrumentation and Control Cables.

The objectives of this task are to:

- provide HRA support to the dry cask PRA; and
- provide HRA support to other nuclear materials and waste risk assessment activities, as needed.

Regarding the dry cask PRA support, the first step of this task is to develop a preliminary understanding of the problem. This will be obtained through document review, a plant visit, and interactions with the licensee.

The second step of this task is to perform a screening analysis to identify the potentially most risk significant human failure events. The HRA method to be used in this step will be selected by discussions among the NRC staff and contractors. Additional information from existing studies, plant procedures, and plant personnel will be used as available. An additional site visit will be arranged to obtain a clear understanding of dry cask storage system operations.

The third step of this task is to develop detailed HRA models (with quantification) for use in the PRA. It is expected that the inputs will appropriately account for uncertainty and work will be required to integrate the results into the overall risk analysis.

Regarding more general nuclear materials and waste applications, it is recognized that the wide variety of facilities and processes of concern to NMSS will likely require the development of a variety of PRA (and HRA) methods and tools. RES plans to initiate work in FY 2002 to, in concert with NMSS, characterize the PRA methods, tools, and data needs for these facilities and processes; Task 8 will provide HRA support to this characterization effort.

The products in this task will be to complete an HRA analysis for dry cask screening assessment and to complete the characterization of HRA needs for NMSS applications.

3.9. Task 9 - Reactor Systems Synergisms and HRA

As pointed out by the ACRS in its recent review of NRC's reactor safety research activities [16], a number of changes in the U.S. nuclear power industry are either underway or are being considered. These changes include plant aging, extended fuel burnups, and licensing actions to allow power uprates. Not only can each of these changes individually affect plant risk levels and profiles, they may have a collective, synergistic effect on risk. However, the risk and phenomenological models needed to assess these risk impacts are not yet well developed.

In FY 2002, RES will initiate a research activity aimed at developing needed methods, tools, and data to assess the collective risk impact of these and other major changes occurring within the industry. The objective of this task (Task 9) is to provide HRA support for the development of risk assessment methods, tools, and data needed to assess the collective impact of major changes in current U.S. NPPs.

Work on developing PRA methods, tools, and data will be initiated in FY 2002. As an early part of this work, a plan for identifying, prioritizing, and addressing key issues will be developed. It is expected that the plan development process will include a review and characterization of major changes, a review of standard NPP PRA assumptions, and an identification of areas where the PRA models may need to be significantly revised. The model review will consider model structure (e.g., success criteria, boundary conditions, cascading effects) as well as parameter values (e.g., failure probabilities, mission times). HRA issues will be considered as part of this overall review effort. The issues are likely to include consideration of potential changes to the time available to operators to perform actions, and of complicating factors that may arise during accidents (e.g., see the discussion on cable aging under Task 7). Other changes that may be considered involve changes in human-related areas (e.g., changes in plant staff size and demographics).

The results of the overall review effort will indicate if existing PRA (and HRA) methods, tools, and data require major or minor changes. It should be noted that RES has sponsored a feasibility study looking at the integration of physical models for key aging mechanisms into conventional PRA structures [34]. The methods and tools developed in that work, together with the results of past studies on PRAs for aging plants, are expected to provide a useful starting point for the treatment of synergistic effects.

The task 9 product will be the identification and characterization of HRA issues for synergistic effects PRA.

3.10. Task 10 - HRA for Upgraded and Advanced Control Rooms

The U.S. Department of Energy has a number of studies underway developing designs for "Generation IV" reactors [35]. As noted by a number of human factors researchers (e.g., see O'Hara [36]), these advanced reactors not only have different operator/plant interfaces (e.g., involving operator navigation through multiple video displays), they also are intended to have fundamentally different roles for the operators in responding to accidents. (For example, the changes may result in the operators' role becoming more one of supervisory control.) These differing interfaces and operator roles are likely to require improvements in current HRA methods and tools in order to support risk-informed design reviews and certifications.

It should also be noted that currently operating plants are gradually upgrading their control rooms by replacing their analog I&C systems with advanced digital systems [14, 37]. These changes are also likely to require improvements in current HRA methods and tools to support risk-informed regulatory applications.

The objectives of this task are to:

- identify key issues associated with HRA for upgraded and advanced control rooms;
- develop guidance for reviewers of HRAs involving upgraded and advanced control rooms; and
- develop improved HRA methods and tools to support PRAs for upgraded and advanced control rooms.

This task, which may be initiated in FY 2002 if funding is available, will involve a review of current trends in control room upgrades, of current proposals for advanced reactors, and of previous studies on the risk implications of advanced control room technology (e.g., see [36]). Based on these reviews, key HRA issues will be identified and the ability of existing methods (including ATHEANA) to address these issues (in light of the information available at a design stage) will be evaluated. Guidance for reviewers of HRAs for upgraded and advanced control rooms will be developed. It is expected that improved HRA methods will be also be developed and demonstrated in a limited test. It is anticipated that these methods will address: a) interactions between the operators, digital protection and control systems, and the plant; and b) any changes in the roles of operators (as compared with current approaches).

In task 10, the product is the identification of key HRA issues for upgraded and advanced control rooms.

3.11. Task 11 - Latent Errors in HRA

The staff has recently completed a study which suggests that latent errors, i.e., errors which occur prior to an initiating event but which are not revealed until some later point in time due to a triggering event (e.g., an accident scenario), may have more impact on plant risk than previously recognized, and that they may require improved treatment in HRAs [38].

Current PRA treatments of latent errors are varied. Some studies address these errors explicitly (as separate contributors to component, train, or system unavailability), while others treat them implicitly (through the failure probabilities assigned to the hardware). The modeling choice is generally dependent on the form of the data used to estimate unavailabilities (e.g., whether failures due to human error are distinguished from other failures).

A number of currently available HRA methods, e.g., THERP, appear to be capable of dealing with individual latent errors and their effects [39]. However, these methods do not deal with a potentially significant issue: systematic dependencies among latent errors, e.g., due to such factors as common work processes [40]. This issue may be important because, if the dependencies are significant, their cumulative impact on multiple HFEs and multiple sequences may alter a plant's risk profile.

The objectives of this task are to:

- develop an improved understanding of latent errors observed during operational events;
- determine where HRA improvements are needed to improve the treatment of latent errors; and
- develop improved HRA methods to identify, model, and quantify latent errors.

The first step of this task will involve the review and evaluation of the latent errors identified in the PHP study. The evaluation shall consider the structure of current PRA component failure databases (to determine how the observed errors are addressed), and of current HRA methods (to determine the extent to which they can be used to model these errors. The evaluation is expected to result in recommendations regarding how current HRA methods can be best used, as well as regarding where improvements are needed.

The second step, which can be performed in parallel with the first, will involve an analysis of operational data for failures that were or may have been caused by latent errors, to determine if there is evidence for dependencies between these failures. This analysis will consider but will not be limited to common cause failure data, as it will consider events involving different components, different systems, and at different times.

The third step will develop improved methods for treating latent errors. The thrust of this work will naturally depend on the results of the preceding tasks. However, it is currently anticipated that the issue of dependencies will need to be addressed, and that organizational considerations (e.g., work processes) will need to be treated in order to address these dependencies. It is also anticipated that results from ongoing international research efforts in this area (e.g., including the work of the International Cooperative Program on PRA Research (COOPRA) working group on organizational influences on risk) will be needed for this step.

The final step will involve an application of the improved methods. The application will revisit the conclusions of the PHP study, and will provide insights regarding the risk significance of latent errors, as well as insights regarding the usability of the improved methods.

Task 11 will produce a review and evaluation of observed latent errors.

3.12. Task 12 - HRA Extended Applications

To date, much of the emphasis of HRA methods development activities worldwide has been on the treatment of HFEs associated with control room actions taken to prevent core damage within a few hours after an initiating event. As many of these methods are based on a general understanding of human behavior and the sources of error, they should be applicable when dealing with other situations (e.g., post-initiator actions outside of the control room, long term recovery actions, actions taken during severe accidents, and actions during low power and shutdown operation). However, these other situations provide challenges (e.g., regarding the treatment of teamwork, the interactions of multiple teams, the availability and quality of indications, the impact of the use of guidelines rather than specific procedures, the extended time available for actions) whose practical treatment may require additional developments.

The objectives of this task are to:

- evaluate existing HRA methods; and
- develop, as needed, improved HRA methods and tools

for the following situations:

- post-initiator actions outside of the control room
- low power and shutdown (LP&SD) operation
- long-term recovery of slow-moving accidents
- severe accidents

For each situation, this task will identify the key features that need to be addressed, and will evaluate existing HRA methods (including both widely used methods as well as recently developed methods) with respect to their ability to practically address these features. Areas for improvement will be identified and improved methods or tools (including guidance) developed, as needed.

The first two areas to be addressed are ex-control room actions and LP&SD operation. Work will be initiated on these in FY 2002. Work on severe accidents HRA will be initiated in FY 2003, and work on long-term recovery actions will be initiated in FY 2004. It is expected that the work on severe accidents HRA will benefit from the (more limited) analyses performed to support severe accident-induced SGTR model development (see Task 6, Section 3.6).

The products from task 12 are improved methods and tools for ex-control room activities and low-power and shutdown PRA.

3.13. Task 13 - Formalized Methods: Screening, Individual and Crew Modeling

The ACRS review of ATHEANA [15] and the results of previous peer reviews have identified a number of specific areas where ATHEANA (as documented in NUREG-1624, Rev. 1 [12]) can be improved. One area, the process for quantifying HFE probabilities, is being addressed by Task 3. Task 13 addresses other areas identified, including the lack of a formal screening method, the lack of an explicit model of cognition for individual crew members (e.g., to provide more formal links between error forcing contexts, potential error mechanisms, and unsafe acts), and the lack of an explicit model for addressing interactions within a crew. Regarding the latter two issues, it is expected that the development of explicit models will improve the accuracy of HRA predictions, reduce the reliance of the analysis results on the judgment of the particular analysis team involved, and will provide an improved means for incorporating experimental data into the analysis (e.g., to test implicit hypotheses built into the analysis, to the assess the strength of specific model factors).

This task is scheduled to start in FY 2003, in order to take advantage of the ongoing tasks (including the ATHEANA applications to various situations), and of anticipated input from ongoing cooperative research activities (e.g., work being conducted by the risk working group (WGRISK) of OECD/CSNI).

The objectives of this task are to:

- develop a screening method for use in context-based HRA methods; and
- develop and test explicit models for addressing individual cognition and team issues for use in HRA.

Regarding the development of a screening method, the previous ATHEANA applications for PTS, fire, and SGTR will be reviewed. The purpose of the review will be to characterize how screening was done in those previous analyses, and to identify areas for improvements in the process. Based upon the results of this review, and upon an understanding of the information available at different stages of an HRA analysis, a more formal screening method will then be developed. This method will be tested in a limited application.

Regarding the explicit modeling of cognitive and team issues, it is recognized that ATHEANA has been developed to support a conventional (static) PRA model structure, whereas a detailed treatment of operator cognition and team effects may require a modeling approach that explicitly accounts for system dynamics. It is also recognized that there are a number of research activities looking at these effects (including the dynamic PRA work being performed at the University of Maryland [41]). In this task, the results of these ongoing activities will be reviewed to determine how their results can be used within a context-based approach to HRA. The results of this review will be used to propose an improved HRA approach. This proposed approach will be tested, likely using data obtained from Task 1.

Because this task will be initiated in FY 2003, products will defined at that time.

3.14. Support Task A - HRA Research Planning

The objective of this task is to ensure that the HRA Research Program appropriately reflects current research results and progress, and current NRC priorities. The task will produce a bi-annual lessons learned report, as well as updates to the HRA Research Program Plan.

3.15. Support Task B - HRA Results Communication

The objective of this task is to ensure that the HRA Research Program results are efficiently communicated to NRC staff users, cooperative research partners, and to interested members of the public. It will employ standard mechanisms for disseminating research results (e.g., publication of reports, conference papers, and journal papers). In addition, a number of additional mechanisms will be investigated and employed if judged efficient. The additional mechanisms considered will include training activities, workshops and seminars (to be coordinated with other HRA meetings, e.g., professional conferences, WGRISK or COOPRA meetings), and information bases.

3.16. Support Task C - General NRC HRA Technical Support

This task addresses requests for HRA support (e.g., in developing plans to treat an emerging issue) not included in the scope of the other tasks in the HRA Research Program. It involves the provision of HRA support for addressing new issues (e.g., through the performance of scoping-level assessments and the development of initial project plans), the development of responses to reviews and requests for information from oversight committees and the Commission, and the provision of initial HRA support to the PHP in the development of Commission policies regarding human performance issues (e.g., fatigue).

3.17. Support Task D - Industry and International HRA Activities

Recognizing that NRC's resources for HRA research and development are limited, and that there are a number of significant international HRA R&D efforts underway, there is a strong incentive for NRC to try to benefit from these international efforts. In order to accomplish this, NRC needs to actively participate in ongoing international cooperative activities, especially those associated with the risk working group (WGRISK) of OECD/CSNI, and with COOPRA.

WGRISK is currently finishing a task looking at errors of commission (see [42]), has held one HRA workshop in May 2001 (at which this paper was presented), and plans to hold another in the near future.

COOPRA has a working group interested in the effect of organizational influences on risk. The results of this working group's activities are expected to provide useful information to Task 11 ("Latent Errors in HRA") and Task 13 ("Formalized Methods: Screening, Individual and Crew Modeling").

Regarding industry efforts, as discussed at the May 2001 WGRISK workshop, the Electric Power Research Institute (EPRI) has initiated an HRA/PRA Tools Users Group aimed at: a) helping industry converge on common HRA methods, and b) enabling different analysts to obtain comparable results for similar situations. The users group is developing an "HRA Calculator," is considering the use of a 2nd generation HRA method developed by EdF (MERMOS [43]), and is considering the quantification of the impact of organizational factors on safety.

The objectives of Task D are to:

- support the exchange of HRA research information; and
- develop targeted cooperative HRA research activities to support NRC's HRA Research Program objectives.

The primary activities under this task will be to support both WGRISK and COOPRA in their HRA activities, including workshops and working groups and task groups. In addition to these formal activities, the possibility of alternative, less formal interactions with selected HRA R&D programs on specific topics (e.g., common terminology and models, HRA methods benchmarking and validation) will be investigated.

4. Program Schedule

Table 3 presents a number of FY 2001-2002 milestones for the NRC HRA Research Program. Additional details on these milestones can be found in Ref. 17. Milestones for FY 2003-2005 will be developed contingent upon the results of ongoing activities.

Table 3. Human Reliability Analysis Research Program Key Milestones, FY 2001-2002

Key Milestone (FY 2001-2002)	**Date**
Complete draft of initial research program plan for review	December 2000
Organize and host WGRISK workshop on errors of commission	May 2001
Complete framework for HRA quantification	June 2001
Develop HRA research lessons to support risk-informed regulatory applications	September 2001
Complete initial evaluation of HRA data needs	September 2001
Present proposed quantification process at WGRISK workshop	October 2001
Hold first workshop/seminar on key research results	December 2001
Provide HRA input to PTS technical basis analysis report	July 2002
Complete review and evaluation of observed latent errors	September 2002
Complete evaluation of symptom-based procedures data	September 2002
Develop improved methods and tools for LP&SD HRA	September 2002

5. Potential Future Activities

Although considerable progress in the development and deployment of HRA methods is expected by the end of FY 2005, the challenges of predicting human performance and the needs of risk-informed regulation are considerable. Therefore, it can be expected that HRA research, development, and applications activities will be needed beyond FY 2005. In particular, on the research and development side, it can be expected that additional work on collecting and analyzing data; on validating HRA models; and on increasing the ability of HRA to deal with: dynamic plant-operator interactions, organizational influences, advanced systems, and non-reactor systems will be needed. On the applications side, it can be expected that a engineering issues will continue to arise, and that the resolution of these issues will require HRA (as part of PRA).

The specific activities to be addressed and their priorities will be discussed at appropriate times with RES management and the ACRS Subcommittee on Probabilistic Risk Assessment. The plan for post-FY 2005 human reliability analysis research will be developed as part of the process of updating the NRC's Risk-Informed Regulation Implementation Plan, and will be documented as an update to the NRC HRA Research Program Plan.

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