UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

June 1, 2004

MEMORANDUM TO: ACRS Members

FROM: Bhagwat Jain, Senior Staff Engineer
Technical Support Staff

SUBJECT: CERTIFICATION OF THE MINUTES OF THE ACRS JOINT RELIABILITY & PROBABILISTIC RISK ASSESSMENT AND HUMAN FACTORS SUBCOMMITTEES MEETING, APRIL 22, 2004, ROCKVILLE, MARYLAND

The minutes of the subject meeting, issued on May 20, 2004, have been certified as the official record of the proceedings of that meeting. A copy of the certified minutes is attached.

Attachment: As stated

cc
ACRS Members
J. Larkins
R. Savio
H. Larson
S. Duraiswamy
ACRS Staff Engineers

UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

June 1, 2004

MEMORANDUM TO: Bhagwat P. Jain, Senior Staff Engineer
Technical Support Staff

FROM: George Apostolakis, Co-Chairman
Stephen Rosen, Co-Chairman
Joint Subcommittee on Reliability and Probabilistic Risk Assessment and on Human Factors

SUBJECT: CERTIFICATION OF THE MINUTES OF THE ACRS JOINT RELIABILITY & PROBABILISTIC RISK ASSESSMENT AND HUMAN FACTORS SUBCOMMITTEES MEETING, APRIL 22, 2004, ROCKVILLE, MARYLAND

We hereby certify that, to the best of our knowledge and belief, the Minutes of the subject meeting issued May 20, 2004, are an accurate record of the proceedings for that meeting.

George Apostolakis, Co-Chairman   06/01/2004
Date

Stephen Rosen, Co-Chairman   06/01/2004
Date

UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

May 20, 2004

MEMORANDUM TO: G. Apostolakis,
S. Rosen,

FROM: B.P. Jain, Senior Staff Engineer
ACRS/ACNW

SUBJECT: DRAFT MEETING MINUTES OF THE ACRS JOINT RELIABILITY & PROBABILISTIC RISK ASSESSMENT AND HUMAN FACTORS SUBCOMMITTEES MEETING, APRIL 22, 2004, ROCKVILLE, MARYLAND

Attached is a working draft meeting minutes of the ACRS joint Subcommittees on Reliability and Probabilistic Risk Assessment and on Human Factors held on April 22, 2004, with representatives of the staff and its contractors. The purpose of this meeting was to review the staff's proposed guidance on 'Good Practices for Implementing Human Reliability Analysis (HRA)' and development of data for Human Event Repository and Analyses (HERA).

Please review and provide me your comments as soon as possible in order the Minutes can be certified by May 28, 2004, my last day with the ACRS.

cc: ACRS Members
J. Larkins
R. Caruso
S. Duraiswamy

Certified By
George Apostolakis
Stephen Rosen

Issued: 05/20/2004
Certified 06/01/2004
06/01/2004

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
JOINT RELIABILITY & PROBABILISTIC RISK ASSESSMENT AND HUMAN FACTORS SUBCOMMITTEE MEETING
GOOD PRACTICES FOR IMPLEMENTING HUMAN RELIABILITY ANALYSIS (HRA)

APRIL 22, 2004
ROCKVILLE, MARYLAND

Introduction

The ACRS Subcommittees on Reliability and Probabilistic Risk Assessment and on Human Factors held a joint meeting on April 22, 2004, with representatives of the staff and its contractors. The purpose of this meeting was to review the staff's proposed guidance on 'Good Practices for Implementing Human Reliability Analysis (HRA)' and development of data for Human Event Repository and Analyses (HERA). Mr. Bhagwat Jain was the Designated Federal Official (DFO) for this meeting. The meeting was convened at 8:30 a.m. and adjourned at 3:15 p.m.

Attendees

ACRS Members/Staff	NRC Staff	Contractors and Industry
George Apostolakis(Co-Chairman)	Erasmia Lois (RES)	Bruce Hallbert (INEEL)
Stephen L. Rosen (Co-Chairman)	Susan Cooper (RES)	Alan Kolaczkowski (SAIC)
Graham Leitch (Member)	David Lew (RES)	Andreas Bye (Halden Reactor Project)
Dana Powers (Member)	Andy Kugler (RES)	John Forester (SNL)
Mario V. Bonaca (Member)	William Krotiuk (RES)	Jeff Brewer (SNL)
Thomas S. Kress (Member)	Selim Sancaktar (RES)	
Victor R. Ransom (Member)	J. Bongarra (NRR)	
Bhagwat Jain (DFO)	Lumbros Lais (NRR)	
	Jiang Hong (NRR)	

A complete list of all attendees is attached to the Office copy of these Minutes.

The presentation slides and handouts used during the meeting are attached to the Office Copy of these minutes. The subcommittee received neither written comments nor requests for time to make oral statements from members of the public.

Background

The staff has developed a Draft Letter Report (JCN W6994), "Good Practices for Implementing Human Reliability Analysis (HRA)," dated April 6, 2004. The draft letter report is intended for performing and reviewing HRAs and as a supporting document to Regulatory Guide 1.200, " An approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities." Regulatory Guide 1.200 describes an acceptable approach for determining the technical adequacy of PRA results for risk informed activity, and reflects and endorses guidance provided by available documents such as the American Society of Mechanical Engineers standard for PRA and the Nuclear Energy Institute PRA Peer Review Process Guidance (NEI-00-02). Since the guidance provided in these documents is at a high level, there is a need to develop more detailed guidance. The staff's Draft Letter Report is intended to fulfill this need. The staff is seeking Committee's views on the Draft Letter Report and concurrence for publishing it for public comment.

Opening Remarks (G. Apostolakis and S. Rosen , ACRS)

Co-Chairman Apostolakis convened the meeting and summarized the agenda and the purpose of the meeting.

Staff Introduction (Erasmia Lois, RES)

Dr. Lois provided an overview of the HRA program. She stated that the staff will discuss the status and results of HRA activities that include HRA good practices, quantification of A Technique for Human Event Analysis (ATHEANA), plans for improving ATHEANA practices, human event repository and analysis, and Halden reactor project HRA activities.

A. HRA Good Practices (A. Kolaczkowski, SAIC, E. Lois, NRC-RES, S. Cooper, NRC-RES, J. Forester, SNL)

Mr. Kolaczkowski stated that the purpose of the guidance regarding 'Good Practices for Implementing Human Reliability Analysis' is to ensure some level of consistency and quality in HRA analyses and their review.

Dr. Apostolakis stated that the report will benefit from a formal peer review by domestic and international experts. Their participation in the development of the report will provide the additional, and very important, benefit of contributing to its acceptance by the international community. Therefore, the staff should organize such a review. Dr. Lois stated that the staff will discuss this with its management.

Dr. Lois mentioned that the staff's "HRA Good Practices" guidance is being developed in two phases. The first phase is the development of this "HRA Good Practices" document which has been prepared on the basis of the staff's experience and lessons learned from developing HRA methods (e.g., ATHEANA), and performing and reviewing HRAs. The second phase is a review and evaluation of existing HRA approaches for their capability to meet the good practices when employed to address different regulatory applications.

Dr. Lois stated that the "HRA Good Practices" document describes the staff's views regarding good practices of a HRA as implemented within a broader PRA framework. As with any evolving technology, both PRA and the implementation of HRA within the PRA framework are continuing to improve. Hence, what is good practice today may be somewhat inferior or outdated tomorrow.

Dr. Lois and Mr. Cooper presented bases and approach for and the scope of the HRA good practices. The presentation included overall and general good practices, pre and post- initiator human event good practices, identification of potential pre and post-initiator human failures, modeling of specific human failure events, and quantification of the corresponding human event probabilities.

Mr. Kolaczkowski stated that the good practices document provides guidance for performing a good HRA, whether for the first time or when analyzing a change to current plant practices. The guidance focuses on the attributes of a good HRA regardless of the specific methods or tools that are used. The good practices guidance does not endorse nor is it meant to suggest that a specific method or tool be used since many methods exist, and all have strengths and limitations regarding their use and applicability. The guidance is specifically for HRAs for reactors operating at full power and internal events applications although most of the guidance may prove to be useful for other applications (e.g., external events, other operating modes) as well. The guidance is very useful for assessing the quality of HRAs. In this regard, the practices of a good HRA are provided which should be useful in formulating questions about and measuring the "goodness" of a HRA. Its purpose is not to explicitly provide questions a reviewer should ask, but rather to provide the technical basis for developing questions or a standard review plan for the staff's review of a HRA.

Mr. Leitch asked whether the HRA good practices document address a specific methodology. Dr. Lois stated that since each method has its own strength and weakness, the good practice document does not endorse any particular method.

Dr. Apostolakis, Mr. Rosen, and Dr. Kress provided several comments on the good practices document, for instance: the uncertainty needs to be assessed in the human event probability (HEP) and not in the mean values for each HEP; usage of the phrase 'recovery actions' in section 5.4 needs to be clarified; and the guidance on errors of commission should be enhanced. In response, Dr. Lois stated that the staff will address these and other comments by the members in the final guidance report.

B. <u>ATHEANA Quantification (John Forester, SNL)</u>

Mr. Forester of Sandia National Laboratories (SNL) discussed staff's quantification approach and treatment of uncertainty in ATHEANA. The staff developed ATHEANA, a HRA method, to increase the degree to which human reliability analyst can represent the kind of human behaviors seen in accidents and near-miss events at nuclear power plants. Mr. Forester stated that an expert elicitation approach has been developed to estimate probabilities for unsafe human actions based on error-forcing contexts (EFCs) identified through the ATHEANA search process. The expert elicitation approach integrates the knowledge of informed analysts to quantify unsafe human actions and treat uncertainty ('quantification-including-uncertainty').

Mr. Forester explained that the analysis focuses on:

(a) the PRA sequence EFCs for which the unsafe human actions are being assessed,

(b) the knowledge and experience of analysts (including trainers, operations staff, and PRA/human reliability analysis experts), and

(c) translation of information into probabilities useful for PRA purposes.

Mr. Forester then described a facilitator led, consensus expert judgment process which integrates the knowledge of informed analysts (trainers, operators, plant PRA/HRA staff) to quantify unsafe human actions and treat uncertainties based on NUREG/CR-6372, "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts." The expert elicitation approach emphasizes asking the analysts what experience and information they have that is relevant to the probability of failure rather than simply asking the analysts their opinion about failure probabilities. The facilitator then leads the group in combining the different kinds of information into a consensus probability distribution.

Mr. Forester stated that in their analysis, they consider several sources of information such as licensing event reports (LERs) and augmented inspection team (AIT) reports. With this additional analysis, the intent is to find the information regarding performance shaping factors that may be present in operating experience and contribute to human performance. Dr. Apostolakis and Mr. Rosen asked whether the analysis being done is a root cause analysis. Mr. Forester replied that they are not performing a root cause analysis rather they are trying to integrate the information from various sources (e.g., LERs, AIT reports) and provide as complete a record and description of the events as possible.

Mr. Forester concluded his presentation by providing an example of the quantification process and resulting uncertainty distribution related to failure to isolate a stuck-open atmospheric dump valve within 30 minutes of the initiating event.

D. Plans for Improving ATHEANA Practices (Susan Cooper, NRC-RES)

Dr. Cooper discussed the staff's plans for improving ATHEANA practices and to make it more user friendly. In the past, the ACRS has characterized ATHEANA implementation being too cumbersome and that the document (NUREG -1624, "Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA)," is voluminous. Dr. Cooper informed the joint Subcommittee that the staff is planning to publish an addendum to NUREG/CR-1624 that will delete lengthy description of the knowledge base and include a description of HRA process, search process for human failure events, lessons learned from ATHEANA applications (including illustrative examples), and up-to-date approaches to ATHEANA quantification and uncertainty analysis. Dr. Powers asked if there are any ATHEANA user groups and Dr. Cooper responded that she is not aware of any such groups. Mr. Leitch wanted to know the difference between ATHEANA and Simplified Plant Analysis Risk (SPAR)-H models. Mr. Hallbert stated that ATHEANA and SPAR-H are different since each one was inspired by different needs and each one suits to different applications. Mr. Hallbert added that SPAR-H was developed to facilitate reviews of operating event information and to develop a method that could be used in updating the conditional core damage probability and other risk metrics.

E. Human Event Repository and Analysis (HERA) (B. Hallbert, INEEL)

Dr. Lois stated that the objective of HERA is to extract information on human performance from operational experience, simulators, and the open literatures and make it more readily available to human reliability and human factor analysts. HERA supports better integration of existing human performance information into rulemaking, licensing and oversight, for example, license applications for plant modifications, evaluation and feedback to licensee programs, and the identification of safety concerns. Mr. Hallbert stated that HERA is an effort to develop data that are relevant and qualified for use in HRA. The objective of HERA is to provide information about human performance in PRA-relevant settings that includes information about conditions affecting the outcomes consistent with HRA methods. Dr. Apostolakis and Mr. Rosen asked if the HERA information will be made available to the experts. Mr. Hallbert replied that the information can be made available to experts but the current set up of HERA system does not have an user interface. Dr. Lois clarified that the intent here is more for the analyst to chose event situations that are similar to those that need to be analyzed and create a distribution that would help the analyst to enhance the decisionmaking capability or update the estimates.

F. Halden HRA Activities (Andreas Bye, HRP)

Mr. Bye of the Halden Reactor Project (HRP) provided an overview of the HRP efforts for designing and performing simulator experiments specifically for HRA. Mr. Bye stated that in order to gain an improved understanding of human performance and reduce uncertainties in HRA and PRA, there is a need for empirical data, specifically for post-initiating event operator actions. He further stated that they performed controlled experiments in realistic settings and the realism was achieved by two simulators of real nuclear power plants, Forsmark 3 (BWR) in Sweden, and Fessenheim (Westinghouse 3-loop PWR) in France. Fessenheim is a sister plant of Ringhals in Sweden and Indian Point 2. Licensed operators and crew from Swedish plants were used in the simulated experiments. The experiments were designed to understand and address cognitive aspects of human performance, decision-based errors and dependencies among actions, performance shaping factors (PSF) and the range of effects of PSFs in accident scenarios, and improve the database for PSFs.

Dr. Apostolakis asked if Mr. Bye had any example to discuss. Mr. Bye provided an example of 'task complexity'. He explained that the task complexity is defined by three items: information load, time pressure, and masking. He further elaborated masking which can mean two things: process of plant conditions (e.g., two parallel faults, one masking the other) and masking by the instrumentation and control. Mr. Bye then provided examples of high complexity scenario in which the element of time-pressure is manipulated when reactor scram occurs. Dr. Apostolakis asked for clarification of the objective of the experiments. Mr. Bye stated that the objective is to study how much the complexity of the task affects human performance.

Subcommittee Comments, Concerns, and Recommendations

Overall, the joint Subcommittee members were satisfied that the staff's Draft Letter Report provides a set of good practices that HRA analysts should follow regardless of the particular model that they use. Members felt that this is an important first step toward achieving consensus within the HRA community regarding the quantification of human reliability and that the report is ready for public comment. Members believed that the report will benefit from a formal peer review by domestic and international experts. Their participation in the development of the report will provide the additional, and very important, benefit of contributing to its acceptance by the international community. Therefore, the staff should organize such a review.

Staff Commitments

The staff has agreed to brief the full Committee during 512th ACRS meeting on May 5-8, 2004.

Background Material Provided to the Subcommittee Prior to this meeting

1. Subcommittee status report
2. Proposed Schedule
3. "Good Practices for Implementing Human Reliability Analysis (HRA)," Draft Letter Report (JCN W6994), April 6, 2004.
4. J. Forester, D. Bley, S. Cooper, E. Lois, N. Siu, A. Kolaczkowski, and J. Wreathall, "Expert Elicitation Approach for Performing ATHEANA Quantification," *Reliability Engineering and System Safety* 83 (2004) 207-220.

****

Note: Additional details of this meeting can be obtained from a transcript of this meeting available for downloading or viewing on the Internet at "http://www.nrc.gov/ACRSACNW" or can be purchased from Neal R. Gross and Co., Inc., (Court Reporters and Transcribers), 1323 Rhode Island Avenue, NW, Washington, DC 20005 (202) 234-4433

Presentation Slides and Handouts Provided during the Subcommittee meeting

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
JOINT MEETING OF SUBCOMMITTEES ON
RELIABILITY & PROBABILISTIC RISK ASSESSMENT AND HUMAN FACTORS
GOOD PRACTICES FOR IMPLEMENTING HUMAN RELIABILITY ANALYSIS (HRA)
APRIL 22, 2004
ROCKVILLE, MARYLAND

-PROPOSED SCHEDULE-

ACRS Contact: B.P. Jain (301-415-7270)

THURSDAY, APRIL 22, 2004, CONFERENCE ROOM T-2B3, TWO WHITE FLINT NORTH, ROCKVILLE, MARYLAND

	Topics	Presenters	Time
I.	**Opening Remarks**	G.Apostolakis/S. Rosen ACRS	8:30- 8:40 a.m.
II.	**Introduction**	D. Lew/E. Lois, RES	8:40- 8:50 a.m.
III.	**HRA Good Practices**	A. Kolaczkowski, SAIC	8:50-10:15 a.m.
		BREAK	10:15-10:30 a.m.
IV.	**ATHEANA Quantification**	J. Forester, SNL	10:30-11:45 p.m.
V.	**Plans for Improving ATHEANA Practices**	S. Cooper, RES	11:45-12:00 p.m.
		LUNCH	12:00-1-00 p.m.
VI.	**Human Event Repository and Analyses (HERA)**	B. Hallbert, INEEL	1:00-1:45 p.m.
VII.	**Halden HRA Activities**	A. Bye, Halden	1:45-2:15 p.m.
VIII.	**Subcommittee Discussion**		2:15-2:30 p.m.
	Adjourn		2:30 p.m.

NOTE: Presentation time should not exceed 50% of the time allocated for a specific item. The remaining 50% of the time is for Subcommittee questions.

available through the NRC Public Document Room at *pdr@nrc.gov,* or by calling the PDR at 1–800–397–4209, or from the Publicly Available Records System (PARS) component of NRC's document system (ADAMS) which is accessible from the NRC Web site at *http://www.nrc.gov/reading-rm/adams.html* or *http://www.nrc.gov/reading-rm/doc-collections/* (ACRS & ACNW Mtg schedules/agendas).

Videoteleconferencing service is available for observing open sessions of ACNW meetings. Those wishing to use this service for observing ACNW meetings should contact Mr. Theron Brown, ACNW Audiovisual Technician (301/415–8066), between 7:30 a.m. and 3:45 p.m. e.t., at least 10 days before the meeting to ensure the availability of this service. Individuals or organizations requesting this service will be responsible for telephone line charges and for providing the equipment and facilities that they use to establish the video teleconferencing link. The availability of video teleconferencing services is not guaranteed.

The ACNW meeting dates for Calendar Year 2004 are provided below.

ACNW meeting No.	Meeting dates
150	May 25–27, 2004.
151	June 22–24, 2004.
152	July 20–22, 2004.
	August 2004—No Meeting.
153	September 21–23, 2004 (Las Vegas, Nevada).
154	October 19–21, 2004.
	November 2004—No Meeting.
155	December 7–9, 2004.

Dated: March 26, 2004.

Andrew L. Bates,

Advisory Committee Management Officer.

[FR Doc. 04–7313 Filed 3–31–04; 8:45 am]

BILLING CODE 7590–01–P

NUCLEAR REGULATORY COMMISSION

Advisory Committee on Reactor Safeguards; Joint Meeting of the Subcommittees on Reliability and Probabilistic Risk Assessment and on Human Factors; Notice of Meeting

The ACRS Subcommittees on Reliability and Probabilistic Risk Assessment and on Human Factors will hold a joint meeting on April 22, 2004, Room T–2B1, 11545 Rockville Pike, Rockville, Maryland.

The entire meeting will be open to public attendance.

The agenda for the subject meeting shall be as follows:

Thursday, April 22, 2004—8:30 a.m. until 2:30 p.m.

The purpose of this meeting is to discuss the proposed staff guidance on Good Practices for Implementing Human Reliability Analysis (HRA) and development of data for Human Event Repository and Analyses (HERA). The Subcommittees will hear presentations by and hold discussions with representatives of the NRC staff, and other interested persons regarding this matter. The Subcommittee will gather information, analyze relevant issues and facts, and formulate proposed positions and actions, as appropriate, for deliberation by the full Committee.

Members of the public desiring to provide oral statements and/or written comments should notify the Designated Federal Official, Mr. Bhagwat P. Jain (telephone 301/415–7270), five days prior to the meeting, if possible, so that appropriate arrangements can be made. Electronic recordings will be permitted.

Further information regarding this meeting can be obtained by contacting the Designated Federal Official between 7:30 a.m. and 4:15 p.m. (e.t.). Persons planning to attend this meeting are urged to contact the above named individual at least two working days prior to the meeting to be advised of any potential changes to the agenda.

Dated: March 26, 2004.

Medhat M. El-Zeftawy,

Acting Associate Director for Technical Support, ACRS/ACNW.

[FR Doc. 04–7314 Filed 3–31–04; 8:45 am]

BILLING CODE 7590–01–P

POSTAL RATE COMMISSION

[Docket No. C2004–1; Order No. 1399]

Periodicals Rate Complaint

AGENCY: Postal Rate Commission.

ACTION: Notice and order on new complaint docket.

SUMMARY: This document announces the Commission's intention to hold hearings on a formal complaint filed by several major Periodicals mailers. The complaint concerns the alleged inconsistency of certain Periodicals rates with several provisions of the Postal Reorganization Act, given several developments affecting the viability of the longstanding rate structure. The Commission also announces several related procedural steps.

DATES: 1. Deadline for filing direct testimony: April 26, 2004.

2. Deadline for filing notices of intervention: May 21, 2004.

ADDRESSES: File all documents referred to in this order electronically via the Commission's Filing Online system at *http://www.prc.gov.*

FOR FURTHER INFORMATION CONTACT: Stephen L. Sharfman, 202–789–6818.

SUPPLEMENTARY INFORMATION: *Summary.* Five mailers who make extensive use of Outside County Periodicals rates have lodged a formal complaint with the Commission pursuant to section 3662 of the1970 Postal Reorganization Act (the Act or the PRA).[1] They assert that the Complaint "concerns fundamental reform of the Periodicals rate structure" in the interest of achieving greater conformity with statutory rate making provisions. Complaint at 4. Complainants contend that the need for such reform is clear, as is the path that should be taken to achieve it. They seek hearings on their allegations regarding the inefficacy of the rate structure and other relief consistent with their claims, including the potential adoption of an alternative rate schedule.

The Commission accepts the Complaint under section 3662, over the Postal Service's objection, and announces its intention to hold hearings under section 3624 to determine whether the allegations in the Complaint are valid.[2] If the Commission finds that to be the case, it will issue a recommended decision on classification changes under section 3623. This decision will not include a rate recommendation.

I. The Time Warner Inc. et al. Complaint

The Complaint includes information addressing applicable Rule 83 provisions, such as identification of the Complainants; a statement of the grounds for the complaint and the

[1] Complaint of Time Warner Inc., Condé Nast Publications, a Division of Advance Magazine Publishers Inc., Newsweek, Inc., The Reader's Digest Association, Inc. and TV Guide Magazine Group, Inc. Concerning Periodicals Rates, January 12, 2004 (Complaint). These mailers are also collectively referred to in this order as Complainants.

[2] The American Postal Workers Union, AFL–CIO (APWU), in a February 13, 2004 letter addressed to the Secretary of the Commission, expressed its opposition to the Complaint. Reasons include the Complaint's reliance on Docket No. R2001–1 rate case assumptions; concern that the proposal is a "radical departure" from the current methodology; the possibility of establishing a poor precedent; the absence of an allegation that current Periodicals rates are illegal; and the alleged inappropriateness of the Commission's interference in the discussion process. The rules of practice do not specifically authorize the APWU's filing at this point in the absence of a motion, but the Commission accepts it and has considered the points it raises in reaching its conclusions.

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

SUBCOMMITTEE MEETING ON HUMAN FACTORS

April 22, 2004
Date

NRC STAFF SIGN IN FOR ACRS MEETING

PLEASE PRINT

NAME	NRC ORGANIZATION
Erasmia Lois	NRC
Andreas Bye	Halden Reactor Project
Per Øivind Braarud	HALDEN REACTOR PROJECT
Bruce Hallbert	INEEL
Susan E. Cooper	NRC
JOHN FORESTER	SANDIA LABS
ALAN KOLACZKOWSKI	SAIC
JEFF BREWER	SANDIA NATIONAL LABS
David Lew	RES
ANDY KUGLER	RES
Lambros Lois	NRR
Gareth Parry	NRR
JIANG HONG	NRR/DE/EEIB
Yung Hsien Chang	UMD
Thiago Pires	UMD.
Selim Sancaktar	RES
Paul Lewis	PRAB
	RES/DRAA/RES
Autumn Szabo	RES
	RES

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS

SUBCOMMITTEE MEETING ON HUMAN FACTORS

April 22, 2004
Date

NRC STAFF SIGN IN FOR ACRS MEETING

PLEASE PRINT

NAME	NRC ORGANIZATION
Molly Keefe	RES
J Bongarra	NRR

From: George Apostolakis <apostola@MIT.EDU>
To: "Bhagwat Jain" <BPJ@nrc.gov>
Date: 5/25/04 10:15AM
Subject: Re: Fwd: DRAFT MEETING MINUTES FOR COMMENTS

BP:

The minutes are fine.

I believe Erasmia has a PhD, so she should be Dr. Lois, not Mrs. Lois. If she doesn't have a PhD, she should be referred to as Ms. Lois.

Good luck.

George

At 04:13 PM 5/20/2004 -0400, you wrote:
>Sorry, missed the attachment.
>Date: Thu, 20 May 2004 16:10:58 -0400
>From: "Bhagwat Jain" <BPJ@nrc.gov>
>To: <historyart@computron.net>, <apostola@MIT.EDU>
>Subject: DRAFT MEETING MINUTES FOR COMMENTS
>Mime-Version: 1.0
>Content-Type: text/plain; charset=US-ASCII
>Content-Disposition: inline
>
>George and Steve:
>
>Attached is a working draft meeting minutes of the ACRS joint
>Subcommittees on Reliability and Probabilistic Risk Assessment and on
>Human Factors meeting held on April 22, 2004, with representatives of the
>staff and its contractors. The purpose of this meeting was to review the
>staff's proposed guidance on 'Good Practices for Implementing Human
>Reliability Analysis (HRA)' and development of data for Human Event
>Repository and Analyses (HERA).
>
>Please review and provide me your comments as soon as possible (PREFERABLY
>IN ELECTRONIC FORMAT or FAX 301-415-5589)
> in order the Minutes can be certified by May 28, 2004, my last day with
> the ACRS.
>
>Thanks
>

Dr. G.E. Apostolakis
Professor of Nuclear Engineering
Professor of Engineering Systems
Room 24-221
Massachusetts Institute of Technology
Cambridge, MA 02139-4307, USA

e-mail: apostola@mit.edu
tel: +1-617-252-1570
fax: +1-617-258-8863

United States
Nuclear Regulatory Commission

Human Reliability Analysis Program
Overview

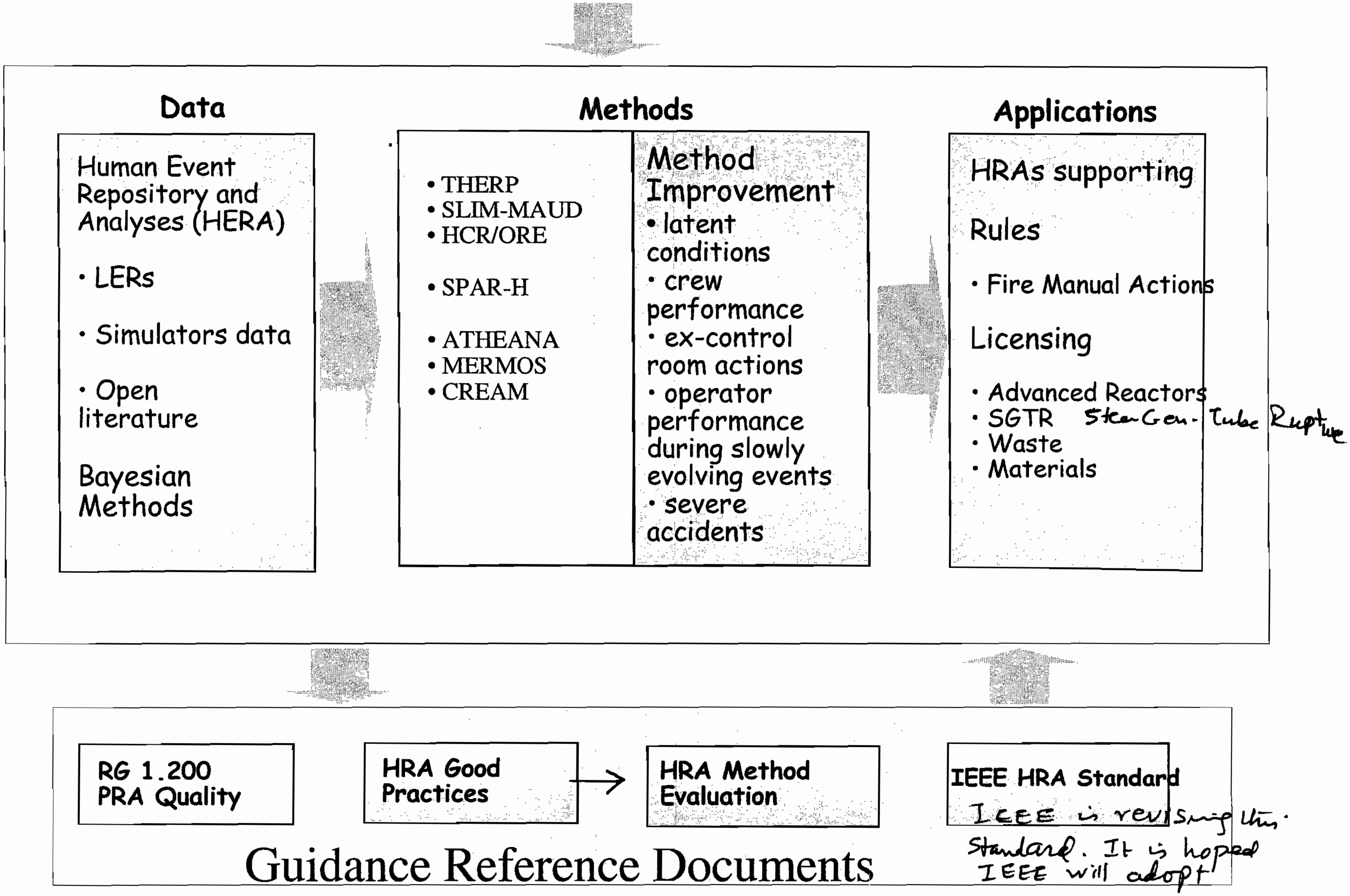
David Lew, Erasmia Lois, Susan Cooper
Division of Risk Analysis and Applications
Office of Nuclear Regulatory Research

Presented to
Joint Meeting of Subcommittees on
Reliability & Risk Assessment and Human Factors
Advisory Committee on Reactor Safeguards
USNRC Headquarters • Rockville, MD • April 22, 2004

Briefing objective and overview

- Objective
  - Discuss status and results of HRA activities
  - Obtain feedback and guidance
- Overview
  - HRA good practices
  - ATHEANA quantification and implementation
  - HRA data development
  - Halden HRA activities

Human Reliability Analysis Activities



Data

Human Event Repository and Analyses (HERA)

- LERs
- Simulators data
- Open literature

Bayesian Methods

Methods

- THERP
- SLIM-MAUD
- HCR/ORE
- SPAR-H
- ATHEANA
- MERMOS
- CREAM

Method Improvement

- latent conditions
- crew performance
- ex-control room actions
- operator performance during slowly evolving events
- severe accidents

Applications

HRAs supporting

Rules

- Fire Manual Actions

Licensing

- Advanced Reactors
- SGTR Steam Gen. Tube Rupture
- Waste
- Materials

RG 1.200 PRA Quality

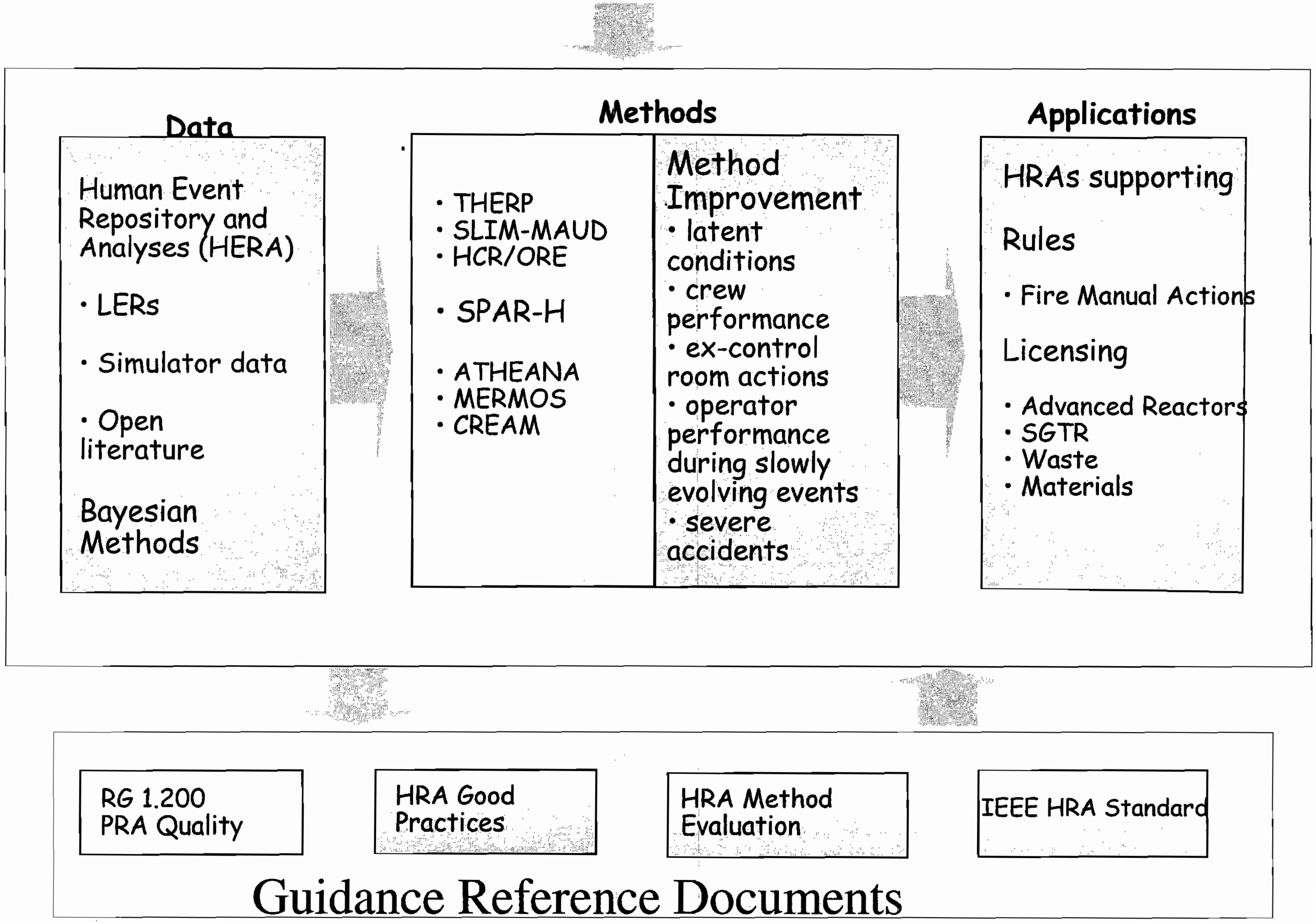
HRA Good Practices → **HRA Method Evaluation**

IEEE HRA Standard

IEEE is revising this. Standard. It is hoped IEEE will adopt

Guidance Reference Documents

HRA activities dicussed today



Data

Human Event Repository and Analyses (HERA)

- LERs
- Simulator data
- Open literature

Bayesian Methods

Methods

- THERP
- SLIM-MAUD
- HCR/ORE
- SPAR-H
- ATHEANA
- MERMOS
- CREAM

Method Improvement

- latent conditions
- crew performance
- ex-control room actions
- operator performance during slowly evolving events
- severe accidents

Applications

HRAs supporting

Rules

- Fire Manual Actions

Licensing

- Advanced Reactors
- SGTR
- Waste
- Materials

RG 1.200 PRA Quality

HRA Good Practices

HRA Method Evaluation

IEEE HRA Standard

Guidance Reference Documents

HRA Guidance

- Supports Reg Guide 1.200/ASME PRA standard
- 3- step Approach
  - Document 1: High level summary of the HRA state-of-the-art
    - Final Dec 04
  - Document 2, "HRA Good Practices," provides technical guidance for performing/reviewing
    - Public Review: July 04
    - Final Dec 04
  - Document 3: Evaluation of 1st and 2nd generation HRA methods w/r to good practices
    - Draft Sept 05
    - Public Review and Comment: June 06
    - Final: Dec 06

Level 1 PRA

major issue is – HRA

Phased approach to PRA Quality

- modeling of model uncertainty
- HRA

GOOD PRACTICES FOR IMPLEMENTING HUMAN RELIABILITY ANALYSIS

Presentation to ACRS

Reliability and Probabilistic Risk Assessment and
Human Factors Subcommittees

April 22, 2004

Alan Kolaczkowski, SAIC

Erasmia Lois, Susan Cooper, NRC-RES

John Forester, Sandia National Laboratories

Issue

HRA is part of the PRA.

- Need to address HRA quality:
  - Consistency in practices
  - Credible applications
- PRA/HRA continuing to be used:
  - Assess current operating risks
  - Estimate Δ risks from plant changes
  - Examine the risks of newer generation plant designs
- HRA results need to sufficiently represent the anticipated operator performance for making risk-informed decisions
- NRC seeks, per SRP 19, that "modeling of human performance is appropriate"
- Reg. Guide 1.200 reflects ASME RA-S-2002 & NEI 00-02
  - These address "what to do" but less on "how to do it"

Solution

- Develop a set of consistent, good HRA practices
  - HRA analysts and reviewers need to know what constitutes "good HRA" for risk decisions
  - Guidance needs to reflect what has been learned in HRA
  - HRA non-experts need to be able to recognize an appropriate HRA

Good HRA or not.

- A "Good Practices for HRA" document is being created
  - Provides working level practices to meet requirements
  - Following these practices will produce the desired HRA
- Working toward a July 2004 Draft for Public Comment and a final version December 2004 for the industry's/NRC's use

BASES & APPROACH FOR HRA GOOD PRACTICES

- Bases for HRA Good Practices
  - ASME Standard Provids significant input.
  - Existing HRA methods and tools
  - Insights from literature (US & Europe)
  - PRA/HRA applications (lesson learned from)
  - Experiences of authors & reviewers of the document
- Approach for development of HRA Good Practices
  - Consensus of experts at NRC
  - Internal NRC reviews
  - ACRS feedback
  - Public comment

Scope of the HRA Good Practices

Document is focused (events that lead to

- Specifically for reactor, full power, internal events; but should be useful for external events, and to some extent other modes & non-reactor applications
- Does not endorse a specific method/tool
- Linked to the ASME Standard – includes summaries of ASME requirements
- Provides possible impacts of not performing good practices and additional remarks
- Focused on HRA process (not, for example, data)
- Many good practices are aimed at ensuring the context for human actions (plant conditions & performance-shaping factors) is addressed in modeling and quantification

HRA Good Practices Are Organized by Logical Analysis Activities

- Overall/general
- Pre-Initiators:
  - Identify potential human failures
  - Screen out from the above human failures those that do not need to be modeled
  - Model specific human failure events (HFEs) corresponding to the human failures
  - Quantify the corresponding human error probabilities (HEPs) for the specific HFEs
- Post-Initiators:
  - Identify potential human failures
  - Model specific HFEs corresponding to the human failures
  - Quantify the corresponding HEPs for the specific HFEs
  - Add recovery actions to the PRA
- Errors of Commission (EOCs)
- HRA Documentation

Overall/General Good Practices

1. HRA is a multi-disciplined, integrated effort within the PRA

2. Some combination of talk-throughs, walkdowns, field observations, and simulations is used as appropriate, to confirm judgments and assumptions

3. HRA addresses both core damage and large early releases

Post-Initiator Human Event Good Practices

Identify Potential Post-Initiator Human Failures

- Covered by 3 GPs that address:
  - GP#1: What to review
  - GP#2: How the review should be done (review process)
  - GP#3: The expected potential human failures that are to be identified
- POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:
  - Model could be incomplete and/or inaccurate, potentially resulting in misinformation as to the risk dominant plant features (including the important human actions).

Model Specific Human Failure Events (HFEs)

- Covered by 2 GPs that address:
  - GP#1: Each HFE is to be modeled as a basic event linked to the affected equipment in the model; criteria are provided for deciding the appropriate level of the modeled basic event (i.e., function, system, train, component level)
  - GP#2: Each HFE needs to be defined based on plant & accident sequence specific characteristics including sequence timing, cues, procedures, training, & location of the act, with insights from talk-throughs, walkdowns, and simulations as necessary
- POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:
  - Allowance for use of generic timing information provided:
    - There is a reasonable basis
    - It is sufficient considering resolution of the HRA quantification tool
  - Misinformation can result as to the risk dominant plant features (including the important human actions); e.g., HFE has wrong effect in the model

Quantify the Corresponding HEPs

- Covered by 8 GPs that address:
  - GP#1: HEPs need to include both cognitive and execution failures
  - GP#2: Conservative HEPs are acceptable provided:
    - Values are clearly over-estimations (generally not lower than 0.1)
    - Dependencies among multiple HFEs in a sequence are accounted for (joint probability of two or more HEPs generally not lower than 0.05)
  - GP#3: Detailed HEPs (not conservative) are needed for dominant human failure contributors
  - GP#4: Analysts need to revisit the use of conservative vs detailed HEPs for each PRA application
  - GP#5: Specific performance-shaping factors (PSFs) are to be considered for each HEP
    - Separate PSFs for in-CR vs. ex-CR actions
    - Some are always considered; others depend on certain conditions
    - Appendix A provides guidance on "measuring" each PSF & addresses interactions among PSFs

Quantify the Corresponding HEPs (continued)

- GP#6: Dependencies among HEPs in a sequence need to be addressed; criteria are provided for deciding the potential for dependency
- GP#7: Mean values and uncertainties (via distributions, sensitivity studies, qualitative analysis) are to be used for the dominant HEPs to the extent necessary to make the relevant risk decision
  - Include both epistemic and important aleatory factors not already addressed in the PRA (e.g. presence, or not, of nuisance alarms)
  - Factors of 10 to 100 are typical between the lower and upper bounds
- GP#8: HEPs need to be reasonable (i.e., make sense)
  - Relative to each other
  - In an absolute sense to the extent that the relevant risk decision is not overly sensitive to the HEP value(s)
  - Strong negative PSFs – HEP ~0.1; strong positive PSFs – HEP ~E-4

- POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:
  - Misinformation can result as to the risk dominant plant features (including the important human actions) especially in light of uncertainties
  - Could inadvertently screen out human actions as unimportant

Add Recovery Actions

- Covered by 3 GPs that address:
  - GP#1: Add recovery actions considering-
    - The failure(s) to be recovered
    - The most logical recovery actions
    - Cues, procedures, training, timing, resources (staffing) available
    - Action is not a repair
    - Equipment needed is accessible and available/operable
  - GP#2: Address dependencies among recovery actions and between the recoveries and the other HFEs in each sequence
  - GP#3: Quantify using relevant data (e.g., offsite power recovery) or HRA analytical techniques
  - Note: these are just another HFE/HEP – prior good practices apply
- POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:
  - Primary concern is applying recovery credit too optimistically

Errors of Commission (EOCs)

- The Good Practices document encourages EOC searches and provides guidance specifically to ensure that future plant changes do not introduce conditions prone to make operators vulnerable to EOCs
- These conditions include:
  - Information input to the operator could lead to a higher potential for misdiagnosis
    - There is a reduction in the redundancy in indications
    - An action will be decided based on just one indication or multiple indications subject to one common fault
  - Procedures and/or training are such that they could lead to a greater chance of implementation errors
    - The procedure/training is ambiguous/unclear
    - Repetitive procedure steps appear to have "no way out"
    - Dilemmas exist without solutions
    - There is a reliance on memory especially for complex or multi-step tasks
    - Calculations or other adjustments are required during time-sensitive situations

Pre-Initiator Human Event Good Practices

Identify Potential Pre-Initiator Human Failures

- Covered by 4 GPs that address:
  - GP#1: What to review (which events to model) Calibration
  - GPs#2-4: What to initially include
    - Actions potentially covered by the affected equipment failure data (i.e., in spite of possibly being covered in equipment data)
    - Actions associated with any other equipment credited in the analysis, e.g., fire barriers, seismic restraints
    - Cases where redundant or multiple diverse equipment can be affected by single or "common mode" failure acts
- POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:
  - Model could be incomplete and/or inaccurate
  - Number of cautions are provided

Screen Pre-Initiator Human Failures

- Covered by 3 GPs that address:
  - GP#1: Criteria provided for screening, e.g., equipment will receive an automatic realignment signal, compelling signal of inoperable status in the CR, etc. (CR = Control Room)
  - GP#2: Does not allow screening pre-initiator failures that simultaneously affect multiple (redundant or diverse) equipment items

    Latent Error
  - GP#3: For "new issues," e.g., plant change, analysts need to revisit the original PRA screening process to ensure issue-relevant human actions have not been deleted from the PRA
- POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:
  - Emphasizes that important pre-initiators can be missed (tend to be those affecting multiple equipment)
  - Number of cautions are provided

Model Specific Human Failure Events (HFEs)

- Covered by 1 GP that addresses:
  - GP#1: How and where to include the HFE in the model
    - Place in the model such that it is linked to the unavailability of the affected component, train, system, or overall function
    - May combine multiple individual acts in a single HFE – addresses relevant criteria:
      - Are the acts and effects related?
      - Will the same performance shaping factors (PSFs) be relevant during quantification?
      - Will some of the acts have dependencies with other actions in the model that might be missed?
    - Clear specification of failure mode reflecting effect of (HFE) ← Latent event.
- POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:
  - The model could misrepresent the effects of each human failure

Quantify the Corresponding HEPs

- Covered by 8 GPs that address:
  - GP#1: Advocates the use of screening values during initial quantification (Human Error Probabilities)
    - Must be over-estimations of HEPs - no lower than 1E-2 for single HPE
    - Conservative accounting for dependencies across multiple actions in a sequence - joint HEP of two or more no lower than 5E-3
  - GP#2: Detailed quantification is needed of significant contributors
  - GP#3: For "new issues," e.g., plant change, analysts need to revisit the original PRA screening process
  - GP#4: Provides PSFs & related guidance to be considered – Cites: procedures, checklists, ergonomics, etc.
  - GP#5: Provides "recoveries" that can be applied, e.g., post-maintenance, calibration tests performed by procedure, shiftly or daily checks, compelling signal, etc.

Quantify the Corresponding HEPs (continued)

- GP#6: Assess dependencies among potentially related actions – addresses commonalities that could cause dependencies and provides quantitative guidelines
- GP#7: Address epistemic uncertainties in the HEP mean estimates (aleatory factors as needed – but generally not applicable). Factors of 10 to 100 are typical between the lower and upper bounds
- GP#8: HEPs need to be reasonable (i.e., make sense)
  - Relative to each other
  - In an absolute sense to the extent that the relevant risk decision is not overly sensitive to the HEP value(s)
  - Strong negative PSFs – HEP ~0.01; strong positive PSFs – HEP ~E-4

- POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:
  - Misinformation can result as to the risk dominant plant features (including missing of important pre-initiator human failures)
  - Cautions are provided

HRA Documentation

- Summary of approach, disciplines involved, and extent that talk-throughs, walkdowns, simulations were used
- Summaries of methods, processes, tools to:
  - Identify pre- and post- human actions
  - Screen pre-initiators from modeling
  - Model HFEs
  - Quantify HEPs
- Assumptions, judgments & their bases including impacts on results/conclusions
- More detail on important HFEs (e.g., PSFs, specific dependencies…)
- Sources of data and their bases for quantification (including uncertainties)
- Results (listing of important HFEs/HEPs) and conclusions

HRA Good Practices Document should be useful to:

- Analysts performing HRA and particularly for plant change submittals
- Reviewers reviewing HRA and when examining plant changes for acceptability

ATHEANA IMPROVEMENT

- ATHEANA Improvement
  - Quantification
    - Addressed ARCS comments on quantification
    - Adopted an expert elicitation process
    - Developed approach to explicitly address uncertainties
    - Used in the PTS PRA
    - Status: completed, CY02
  - Implementation
    - Addressing ACRS concerns for resources needed to apply ATHEANNA
    - Build on lessons learned from applying ATHEANA
    - Create an Addendum to NUREG-1624
    - Technology transfer
    - Status: just initiated

Quantification And Treatment Of Uncertainty In ATHEANA

John Forester, Alan Kolaczkowski, Erasmia Lois and Susan Cooper

Presentation to the Advisory Committee on Reactor Safeguards, PRA and Human Factors Subcommittees

Rockville, MD April 22, 2004

Presented By

John Forester

Other Contributors to the Development of the Quantification Process

- Dennis Bley
- Nathan Siu
- John Wreathall

Issue

- ATHEANA (NUREG-1624, Rev. 1) focused on search process for unsafe acts (including errors of commission) and error forcing context (EFC)
- Quantification process relied on existing HRA methods
- ACRS - Quantification process needed improvement
- ACRS/NRC - HRA quantification needs better treatment of uncertainty

Solution

- Adopted a facilitator led, consensus expert judgment process
- Provides a better approach for incorporating the effects of context as identified and represented in ATHEANA
- Striving for more formal and systematic treatment of uncertainty
- Goal is more realistic results

ATHEANA Prospective Search Process

- Identify important human failure events (HFEs), unsafe actions (UAs) and the contexts that could cause them to occur (EFCs)
- Key aspects:
  - Identify operational vulnerabilities that could set-up potential unsafe actions
    - Procedures, knowledge, biases...
  - Identify potential deviations from expected conditions that might cause problems
    - Are there ways the scenario could evolve that could confuse the crew?

Basic Formulation

- $$P\,(HFE|S) = \sum_{i} P(EFC_i|S) \text{ x } P(UA|EFC_i,S)$$
- HFEs are human failure events modeled in PRA
  - Modeled for a given PRA scenario (S)
  - Can include multiple unsafe actions (UAs) and error-forcing contexts (EFCs)
- First determine probability of the EFC, including plant conditions and performance shaping factors (PSFs)
- Determine probability of UA given the identified EFC

Facilitator Led, Consensus Expert Judgment Process

- Integrates the knowledge of informed analysts (trainers, operators, plant PRA/HRA staff) to quantify UAs and treat uncertainty (Based on SSHAC report, NUREG/CR-6372)
  - Investigates information and “evidence” “brought to the table” by experts
  - Transforms informed judgment into probability distributions
  - Considers a full range of PSFs, though quantification ultimately dependent on those believed most significant
  - Assesses interactions/dependencies between factors in terms of their influence on performance in the context being examined

Step 1 - Guidance to Multidisciplinary Panel About the Process

- Overview of ATHEANA, quantification process, terminology, etc.
- Try to "calibrate" on what the different probabilities mean
  - "Likely" to fail ~ 0.5 (5 out of 10 would fail)
  - "Infrequently" fails ~ 0.1 (1 out of 10 would fail)
  - "Unlikely" to fail ~ 0.01 (1 out of 100 would fail)
  - "Extremely unlikely" to fail ~ 0.001 (1 out of 1000 would fail)
- Analysts are allowed to assign any values to represent the probability of the UA (e.g., 3E-2, 5E-3 can be used)

Step 2 - Structure Scenario Context and Identify Important Aleatory Factors

- Results of ATHEANA prospective search process (UAs and EFCs - vulnerabilities and deviation scenarios)
- <u>Facilitator</u> (with help from analysts) establishes critical set of event and scenario characteristics, PSFs etc.
- $P(UA|EFC_i,S)$
  - EFC_i,S may not initially include everything that can influence performance, e.g, aleatory factors such as crew differences, possible instrument problems, etc
  - HRA/PRA has not typically addressed such factors explicitly
- Created a factor checklist to help identify potentially important aleatory factors, i.e., those could have strong effects and that have a reasonable likelihood of occurring
  - Plant context, crew behavior factors, environmental factors, etc.
  - Compare against factors identified by searches

Step 3 - Translate Contextual Information into a Probability Distribution for a given UA

- Each analyst independently develops a probability distribution for the likelihood of the UA
  - Begin by asking what the worst case for the probability of failure would be (determine 99th percentile)
    - e.g., worst case for reasonably likely/important aleatory factors – middle of the night, least aggressive crew, significant unexpected instrument problems, etc.
  - Next ask what the best case for the probability of failure would be (determine 1st percentile)
  - Estimate UA probability at which 50% of the crews would have a higher failure rate while 50% would have a lower failure rate
  - Fill-in the distribution with other estimates (10th, 25th, 75th, 90th)
- Discuss distributions, facilitator attempts to control for bias, revise distributions, strive toward consensus

What Does the Distribution Represent?

- Each distribution for a given $P(UA|EFC_i,S)$ represents:
  - The probability distribution of a UA given a particular EFC in a given accident scenario, *S,* including the uncertainty due to the effects of strong aleatory factors and “error” in the estimate due to lack of knowledge about the precise effects of all influencing factors (epistemic uncertainty)
- If quantify multiple UAs or EFCs, then would need to combine the obtained distributions for a given HFE

Quantification Example - Failure to isolate a stuck-open atmospheric dump valve (ADV) within 30 minutes

General Context

- Creates a small secondary side depressurization.
- Since the ADV is stuck open, requires that an AO go to the roof and use a “reach-rod” through the wall to perform the isolation.
- While instruction to close any open ADV is indicated in EOP 1.0, the explicit instructions to go onto the roof indicated in EOP 6.0, Step 14.
- Estimated that the crew would get to step in EOP 1.0 in about 5 min. and that it could take 15 min. to diagnose SO ADV, assign AO, and complete the action on the roof.
- Since it was also estimated that it would take about 15 minutes for the crew to reach step 14 in EOP 6.0, crew would probably need to begin the process of getting an AO ready to go before reaching Step 14 in EOP 6.0
- A sheet of instructions are provided to the AO as to how to go up on the roof and isolate the ADV. The action is practiced occasionally

Quantification Example - Failure to isolate a stuck-open ADV within 30 minutes (continued)

Aleatory Factors Addressed

- Instrumentation or controls unavailable due to maintenance or failure. In this case, particularly those displaying ADV position.
- Support system failures that affect control of other systems (can cause very confusing plant response, e.g., instrument air, instrument AC, instrumentation and control system.
- Aggressiveness of the crews with respect to anticipating actions, planning ahead, and “taking control” vs. methodically applying procedures
- Whether they enter EOP 6.0 or EOP 9.0. Entry into EOP 9.0 could lead them to take a little longer to reach the isolation step.
- Crew “having bad day” (for any number of possible reasons), weaker crew, or a minimum crew present at the start of the event.
- Time of day, weather, and random hardware/equipment problems could have an effect on the crew’s ability to complete the action. Limited lighting on the roof and wet, cold, icy, snowy weather could make the task more difficult. Also, if late at night, AOs immediately available to take care of ex-control room actions might be limited.

Quantification Example - Failure to isolate a stuck-open ADV within 30 minutes (continued)

Basis for the Consensus Distribution

- Likely that crew would diagnose the presence of the stuck-open ADV during Step 7 of EOP 1.0.
- But not as clear that all crews would send an AO up to the roof immediately upon reaching Step 7 in EOP 1.0.
- Agreed that if did not send someone during EOP 1.0, most crews would at least begin the process of preparing an AO for the task before reaching Step 14 of EOP 6.0.
- Staff noted that in a recent training simulation of the scenario, an AO was dispatched to the roof to close the ADV during EOP 1.0.
- Agreed that not all crews would initiate the action that quickly – likely to be fairly busy.
- Main considerations for failing to perform the action within 30 minutes (aleatory factors) was
  - Potential for bad weather and problems executing the action.
  - Potential for slow or "non-aggressive" crews
  - Problems with ADV indicators

Uncertainty distributions for: Failure to isolate a stuck-open atmospheric dump valve (ADV) within 30 minutes of the initiating event.

Analysts	Percentiles						
	1st	10th	25th	50th	75th	90th	99th
#1	0.01	0.05	0.08	0.03	0.4	0.8	1.0
#2	0.001	0.003	0.008	0.02	0.07	0.1	0.8
#3	0.001	0.01	0.06	0.03	0.4	0.6	0.9
#4	0.005	0.01	0.02	0.033	0.1	0.6	0.8
Consensus	0.001	0.01	0.03	0.04	0.2	0.5	0.9

Conclusion

- Overall process appears to work well
  - Initial estimates of HEPs and distributions reasonably consistent (order of magnitude)
  - Consensus generally easy to reach (analysts have opportunity to listen to rationale of other analysts after initial estimates obtained)
  - Analysts generally more confident in consensus distribution than in original personal distribution
- In spite of limitations of using expert judgment, best existing approach for a realistic analysis
- Need more operational and empirical data to support HRA

United States
Nuclear Regulatory Commission

IMPROVEMENT TO ATHEANA IMPLEMENTATION

Presented to ACRS
April 22, 2004

Dr. Susan E. Cooper

ISSUE

- ATHEANA Implementation
  - Comments indicate that ATHEANA implementation is cumbersome
  - NUREG-1624 is voluminous
  - Additional work has been done that is not included in NUREG-1624, Rev. 1
  - Applications of ATHEANA have/can provide useful lessons learned

SOLUTION

(Still in Planning Stage)

- Create an Addendum to NUREG/CR-1624
  - Description of up-to-date ATHEANA quantification approach
- Description of up-to-date approach for uncertainty analysis
- Selective focus on HRA tools given in NUREG-1624
  - Exclude knowledge-base, retrospective analysis approach, etc.
  - Include HRA process
  - Include search process for HFEs
  - Include search process for deviation scenarios
- Guidance on "fast-track" approaches for applying ATHEANA
- Lessons learned from ATHEANA applications (including illustrative examples)

Data Development

- Human Event Repository & Analysis (HERA)
  - Effective use of existing information
  - Currently focusing on NPP operational experience
  - Future plans include other sources
  - Status
    - CY 03: Developed prototype and loaded limited number of operational events
    - CY 04 and Beyond
    - Finalize software
    - add events
    - Develop Bayesian type methods to use the events

Idaho National Engineering and Environmental Laboratory

Human Event Repository and Analysis (HERA)

Presentation to the Advisory Committee on Reactor Safeguards

April 22, 2004

Bruce P. Hallbert

Issue

- *HRA influences the uncertainty of PRA results.*
- *The strength of available data for HRA is an important contributor to the uncertainties*
- *Data are needed to build models and estimate probabilities for PRA*
- *While hard data may be sparse information/evidence about human performance is available*
- *Bayesian methods allow the use of this type of information/evidence in estimations*

Solution

- *Human Event Repository & Analysis (HERA):*
  - *an effort to develop data that are relevant and qualified for use in HRA.*
  - *Develop Bayesian methods for using HERA data to estimate human failure event (HFE) probabilities*

Background

- *HRA methods use structured processes to identify potential human failure events and to estimate their likelihood.*
- *Most methods permit or direct the analyst to account for performance conditions and context.*
- *Identifying important conditions and accounting for their effects continue to be a challenge for HRA.*
- *HRA methods may account for different Performance Shaping Factors (PSFs) and may treat them each differently.*
- *As a result, considerable analyst judgment is required.*
- *Differences in the magnitude of effect of such factors contribute to the uncertainty in the resultant risk metric.*

HERA Objective and Approach

- *Objective: Provide information about human performance in PRA-relevant settings that includes information about conditions affecting the outcome(s) consistent with HRA methods.*
  - *Support both human factors and HRA activities*
- *Approach:*
  - *Identify information sources that can be used to inform HRA activities.*
  - *Develop a formal process for analyzing information from sources to extract HRA-relevant information.*
  - *Perform analyses and extract information from candidate information sources.*
  - *Develop a repository that is used with other NRC information systems to make information readily available.*
  - *Develop Bayesian type methods to allow the use of various types of evidence in estimations.*

Human Performance Information Sources

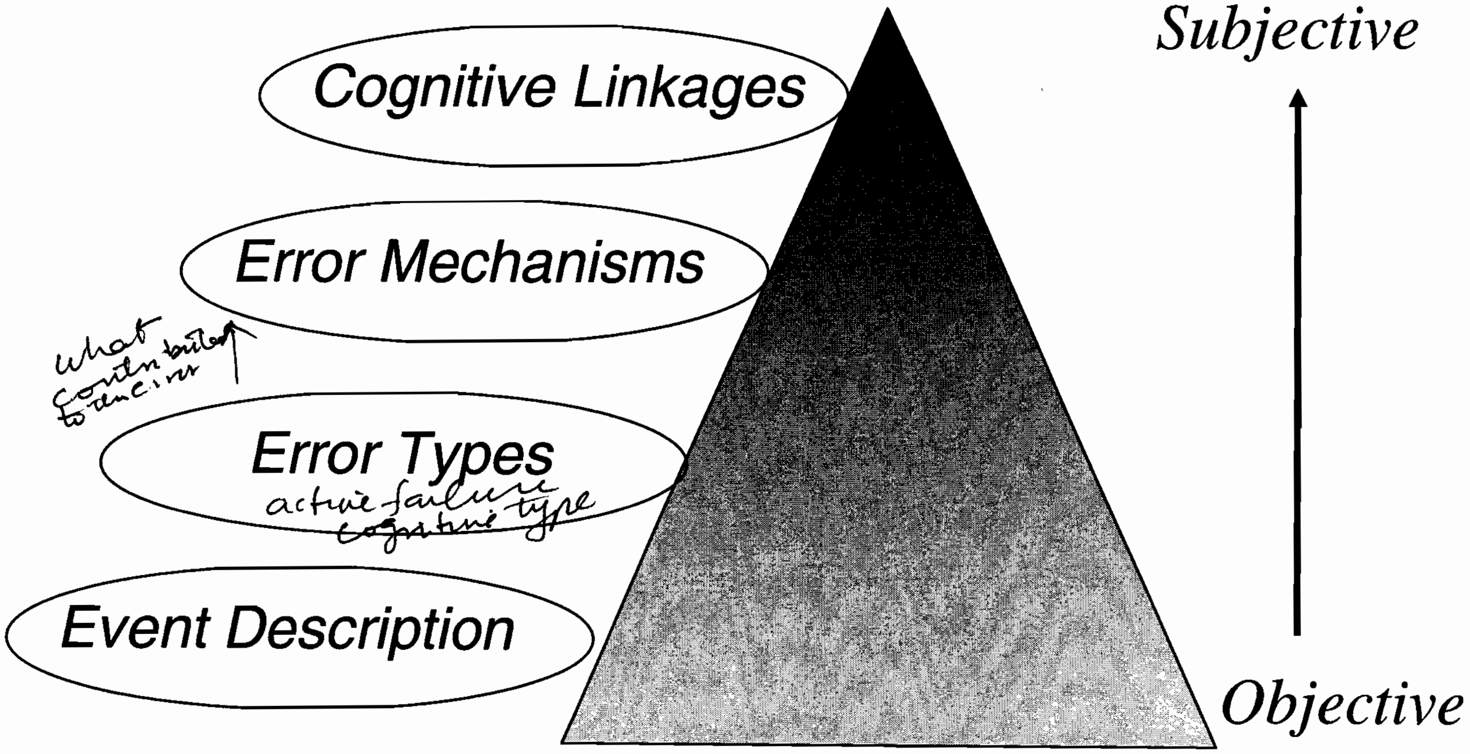
- *Considered several initially: Operating experience; behavioral sciences literature; simulator studies, data from other industries.*
- *Began and are currently working with Operating Experience:* ie LER and Augmented Inspection Team report.
- *Highly applicable to NRC mission; implicitly risk-relevant.*
- *Using an available, NRC- and industry-reviewed, source.*
- *Indicate what kinds of things have gone wrong (as well as right) during events.*
- *Can be used to identify credible Unsafe Acts (UAs) and Human Failure Events (HFEs) given same or similar contexts*
- *Allows for identification and assessment of PSFs*
- *Accounts for the role of personnel during accident mitigation*

HERA Structure

- *Event summary*
  - *Date, Licensee, Plant, Initiating Event, Basic event(s), context(s), operating mode(s), source documents employed.*
- *Graphic timeline and descriptive information for sub events*
  - *Equipment conditions, human failure or success, dependency between sub events.*
- *Performing Organization (e.g., maintenance)*
- *Performance Type and Action or diagnosis task description*
  - *e.g., pre-initiator, initiator, post initiator action or diagnosis*
- *Success or Failure information*
- *Active versus latent failure distinction*
- *PSF information; 8 PSFs used for HFEs and successful actions*
- *Plant conditions (factors contributing to operations and maintenance)*
- *Function, system, and component unavailability*
- *Dependency*

Process model

- *Based on concept of layering:*



Status

- LERs from NRC system studies – EDG failures (12 events)
- Now Processing information from common cause failure events
- 80 data records (end of CY 03)
- Approximately 3 4unsafe acts and two positive human actions (HAs) per LER
- Roughly 9 - 14unsafe acts per AIT

Bayesian framework development

- *Concurrent with information/evidence development, working on method(s) to produce quantitative results.*
- *Bayesian methods*
  - *Use all available information*
  - *Can be used to produce parameter estimates from observations*
  - *Account for causal and conditional nature of performance and context.*
- *Probability is quantification of degree of belief*
- *Begin with a prior distribution about hypothesis*
- *Observe performance*
- *Develop a posterior distribution for hypothesis.*
- *Estimate probability that a hypothesis is true, conditional on all available evidence.*
- *Differs from classical statistical and "frequentist" methods.*

Bayesian Example – Service Water

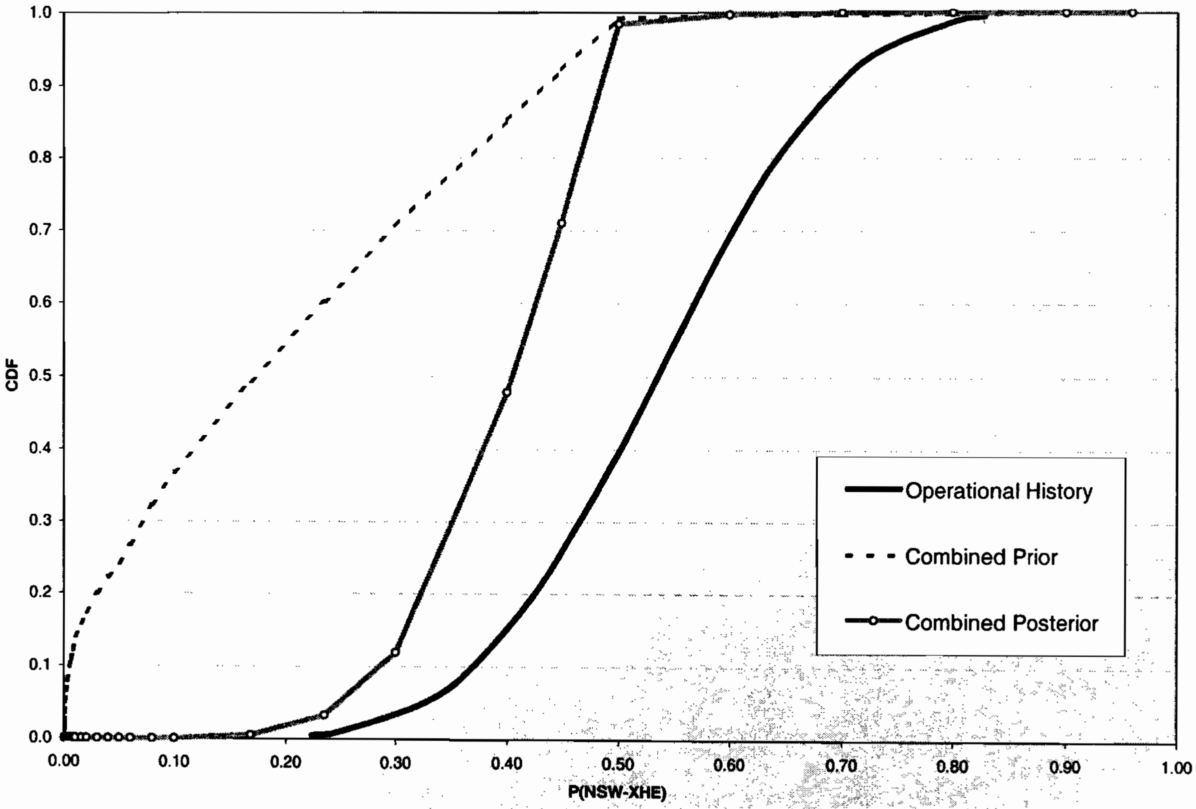
- *Collected recovery of **service water** data, failures versus successes*
  - *We also have four **HRA** results for this recovery*
    - *NUREG/CR-5319, Risk Sensitivity to Human Error*
    - *Nuclear Computerized Library for Assessing Reactor Reliability (NUCLARR)*
    - *Standardized Plant Analysis Risk (SPAR) HRA*
    - *A Technique for Human Event Analysis (ATHEANA)*
- *We could **combine** sources of HRA information to make our prior (includes HRA models, expert elicitation information); joined in example via probability (i.e., in the likelihood function)*

Source	NUREG/CR-5319	NUCLARR	SPAR-H	ATHEANA
~~*Likelihood*~~ weight to the Source	0.1	0.1	0.2	0.6

(How much you believe each method).

Bayesian HRA – Pooled Information

- *With prior from the **pool** of four HRA information sources, we **update** our service water recovery data*



Bayesian HRA – Analysis Types

- *Two types of analysis are possible*
  - ***High** level -- human performance, measured at "sharp end," and represented by fail/succeed*
  - ***Low** level- - human performance from causal interactions that affect performance*
- *Inference methods based upon Bayesian analysis **do not differentiate** between constructs like "high" or "low"*
  - *Are **allowed** to shape Bayes' Theorem into a useful inference tool*

Summary

- *Developing a source of HRA information - HERA - and a framework for employing the information in analyses.*
- *Implementing human performance coding in NRC hardware reliability system.*
- *Develop and demonstrate Bayesian framework for using information from HERA to improve estimation of parameters used in human reliability.*
- *Bayesian framework workshop planned to review:*
  - *Concept of Bayesian Framework*
  - *Examples of Bayesian applications using HERA*
  - *Identify main priorities for framework development.*
- *Working with Halden on cooperative arrangement for integrating results of research into HERA.*

Halden Simulator HRA Studies

- Design simulator experiments specifically for HRA
  - Experimental data is the best thing next to "real"
  - Improve understanding of both successes and failures
  - Examine operator and team performance

- Benefits
  - Capability to test hypotheses employed in HRA methods
  - Achieve rigorous (systems-type) modeling methods

- Status
  - CY03 initial attempts to use the simulator for HRA
  - CY04: more focused experiments

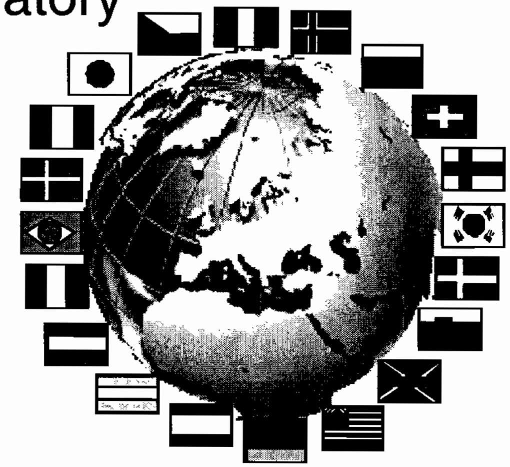
Halden HRA activities

Advisory Committee on Reactor Safeguards
PRA and Human Factors Subcommittees
22 April 2004

Andreas Bye
OECD Halden Reactor Project

OECD Halden Reactor Project (HRP)

- 19 sponsoring member-countries
- 3 year program periods
- Experimental programs
  - Nuclear fuels and materials, Halden Boiling Water Reactor (HBWR)
  - Man – Technology – Organisation
    - HAMMLAB, HAlden huMan Machine LABoratory
    - Virtual Reality (VR) center
- Human Performance
  - **Human Reliability**
  - Design support



- Currently working with NRC on HRA informed research

HRA in Halden

Issue

- Need for empirical data for HRA (CSNI, 2004)
  - Data for post-initiating event operator actions
- Improved understanding of human performance
- Reduced uncertainty of HRA and PRA

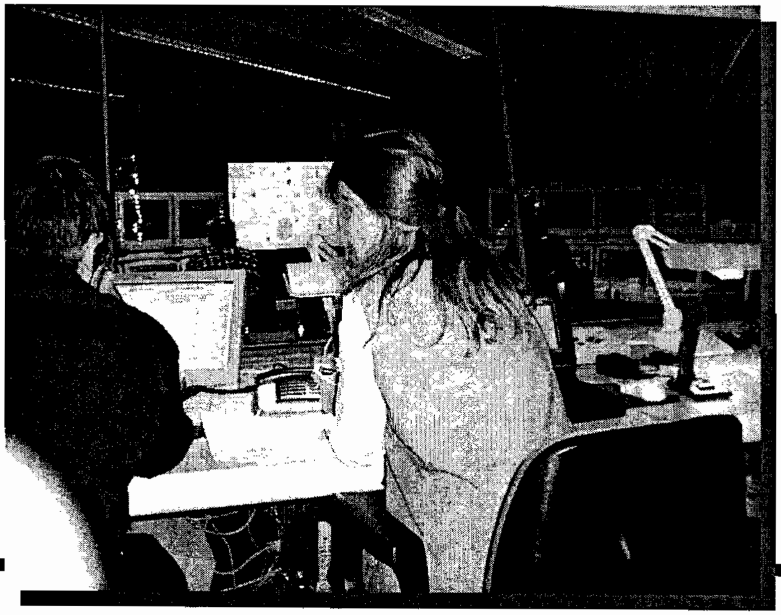
Solution

- Simulator experiments to provide HRA data

(CSNI, 2004) CSNI Technical Opinion Papers No. 4
Human Reliability Analysis in Probabilistic Safety Assessment for Nuclear Power Plants, OECD 2004, NEA No. 5068

HAMMLAB

- Controlled experiments in realistic settings
  - Full-scale simulators of real nuclear power plants
    - Forsmark 3 NPP (ABB Atom BWR)
    - Fessenheim NPP (Westinghouse 3-loop PWR)
    - (Loviisa NPP (VVER))
  - Licensed operators, in crews, from simulated plants
  - PRA relevant scenarios
  - Not replica control room, but computerised



HRA data from simulators

Empirical human performance data for accident situations

- Understanding human performance in accident operation
  - Address cognitive aspects of human performance, why do errors occur
  - Decision based errors
  - Dependencies among actions
- Context, Performance Shaping Factors (PSFs)
  - Focus on specific causal factors
  - Assess the range of effects of PSFs in accident scenarios
  - Improve data basis for PSFs, and interaction between PSFs
    - Through experimental manipulation
- Input to direct quantification
  - Bayesian approach

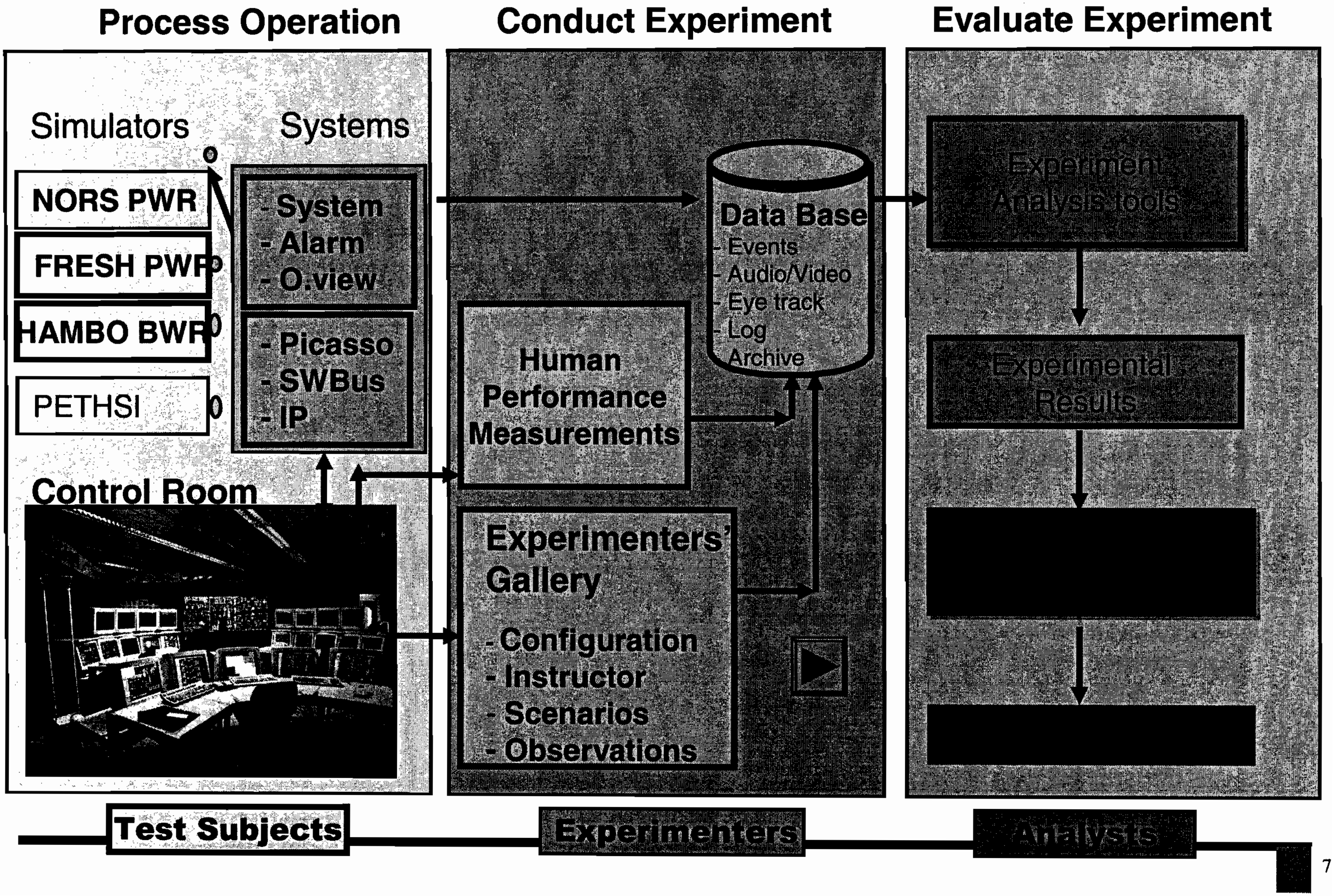
Experiments for HRA

- Task Complexity
  - Example of method, design and measures
  - Task Complexity in our terms defined by
    - Information load
    - Time pressure
    - Masking

I&C

Plant Condition

HAMMLAB Experiment Execution



Process Operation

Conduct Experiment

Evaluate Experiment

Example of Conditions defining Complexity

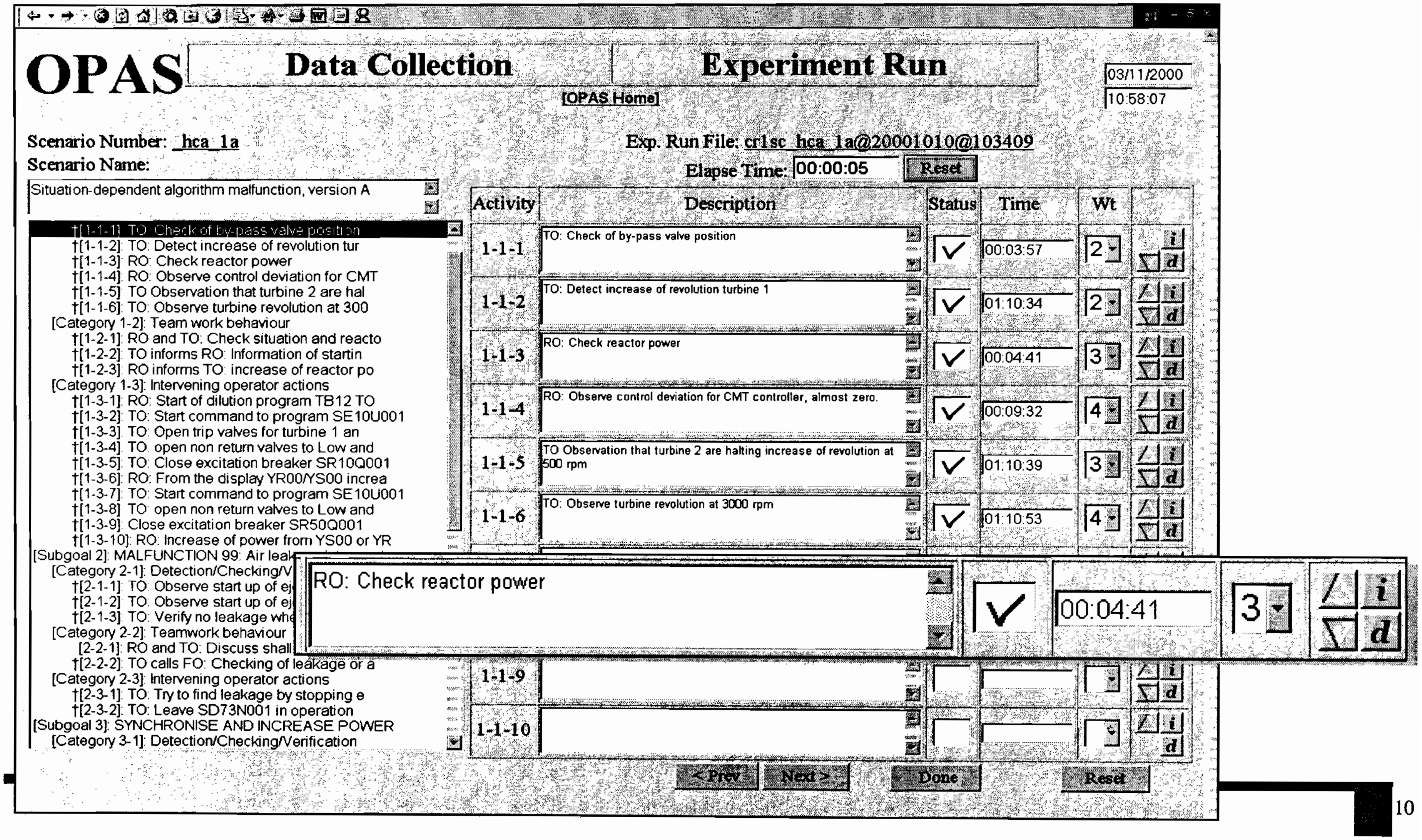
	Time Pressure	Masking	Information Load
High Clx Scenario	• When SCRAM occurs, the closed 314-valve open. If this is not closed immediately, the risk is high for Feedwater Isolation (due to high level in Reactor Tank). .	• The loss of voltage on busbar 641 will last just some seconds. It will be difficult for the operators to understand why relatively many pumps stops and restart. • Indication for released condition for feed water isolation is missing in the 516-picture	• First the loss of voltage on busbar 641 and short time after that Feedwater Isolation (IM). High load because they do not have time to follow up the loss of voltage and IM before containment isolation occurs.
Low Clx Scenario	• Low time pressure. It is possible to use the feed water system a long time. .	• It is reasonably difficult to understand why Turbine Trip (TS) occurs, but it has no direct significance.	•The initial turbine disturbances do not affect Containment Isolation (II). Relatively small load and no problems with the feed water.

Performance data

- OPAS Sheets
  - Detections, situation assessment, planning (observed)
  - Actions (log)
- Safety functions (plant system, components)
  - Log of process and components
- Subject Matter Expert (SME) ratings
- Operator ratings
- Observations
  - Unexpected / deviations
  - Narratives
- Crew's own debriefing after scenario

OPAS (Operator Performance Assessment System)

- Human performance: Operator activities
  - Detection, Situation Assessment, Planning, Action



03/11/2000
10:58:07

Scenario Number: hca 1a

Scenario Name:

Situation-dependent algorithm malfunction, version A

Exp. Run File: cr1sc hca 1a@20001010@103409

Elapse Time: 00:00:05 Reset

†[1-1-1] TO Check of by-pass valve position
†[1-1-2]: TO: Detect increase of revolution tur
†[1-1-3]: RO: Check reactor power
†[1-1-4]: RO: Observe control deviation for CMT
†[1-1-5]: TO Observation that turbine 2 are hal
†[1-1-6]: TO: Observe turbine revolution at 300
[Category 1-2]: Team work behaviour
†[1-2-1]: RO and TO: Check situation and reacto
†[1-2-2]: TO informs RO: Information of startin
†[1-2-3]: RO informs TO: increase of reactor po
[Category 1-3]: Intervening operator actions
†[1-3-1]: RO: Start of dilution program TB12 TO
†[1-3-2]: TO: Start command to program SE10U001
†[1-3-3]: TO: Open trip valves for turbine 1 an
†[1-3-4]: TO: open non return valves to Low and
†[1-3-5]: TO: Close excitation breaker SR10Q001
†[1-3-6]: RO: From the display YR00/YS00 increa
†[1-3-7]: TO: Start command to program SE10U001
†[1-3-8]: TO: open non return valves to Low and
†[1-3-9]: Close excitation breaker SR50Q001
†[1-3-10]: RO: Increase of power from YS00 or YR
[Subgoal 2]: MALFUNCTION 99: Air leak
[Category 2-1]: Detection/Checking/V
†[2-1-1]: TO: Observe start up of ej
†[2-1-2]: TO: Observe start up of ej
†[2-1-3]: TO: Verify no leakage whe
[Category 2-2]: Teamwork behaviour
[2-2-1]: RO and TO: Discuss shall
†[2-2-2]: TO calls FO: Checking of leakage or a
[Category 2-3]: Intervening operator actions
†[2-3-1]: TO: Try to find leakage by stopping e
†[2-3-2]: TO: Leave SD73N001 in operation
[Subgoal 3]: SYNCHRONISE AND INCREASE POWER
[Category 3-1]: Detection/Checking/Verification

Activity	Description	Status	Time	Wt
1-1-1	TO: Check of by-pass valve position	✓	00:03:57	2
1-1-2	TO: Detect increase of revolution turbine 1	✓	01:10:34	2
1-1-3	RO: Check reactor power	✓	00:04:41	3
1-1-4	RO: Observe control deviation for CMT controller, almost zero.	✓	00:09:32	4
1-1-5	TO Observation that turbine 2 are halting increase of revolution at 500 rpm	✓	01:10:39	3
1-1-6	TO: Observe turbine revolution at 3000 rpm	✓	01:10:53	4
1-1-9				
1-1-10				

Description	Status	Time	Wt
RO: Check reactor power	✓	00:04:41	3

Subjective Complexity Questionnaire

1. Unclear or Ambiguous process picture, misleading or missing process indication	**Very difficult**	☐ 1	☐ 2	☒ 3	☐ 4	☐ 5	☐ 6	☐ 7	**Easy**
2. Ambigious, misleading or missing process feedback on process actions	**Very difficult**	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	**Easy**
3. Unexpected or ambiguous process development given the actual event	**Very difficult**	☐ 1	☐ 2	☒ 3	☐ 4	☐ 5	☐ 6	☐ 7	**Easy**
4. Time available to assess the process situation	**Very difficult**	☐ 1	☒ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	**Easy**
5. Time available to carry out needed actions	**Very difficult**	☐ 1	☐ 2	☐ 3	☐ 4	☒ 5	☐ 6	☐ 7	**Easy**
6. Time available to plan and verify work	**Very difficult**	☐ 1	☐ 2	☐ 3	☐ 4	☒ 5	☐ 6	☐ 7	**Easy**
7. Many simultaneous tasks making it difficult to perform the individual tasks	**Very difficult**	☐ 1	☐ 2	☐ 3	☒ 4	☐ 5	☐ 6	☐ 7	**Easy**
8. Collecting and using large amount of information was required to do the work	**Very difficult**	☐ 1	☒ 2	☐ 3	☐ 4	☐ 5	☐ 6	☐ 7	**Easy**
9. Conflicting tasks	**Very difficult**	☐ 1	☐ 2	☒ 3	☐ 4	☐ 5	☐ 6	☐ 7	**Easy**

PSF rating Questionnaire

1. Procedures
2. Training/experience
3. Indications in HMI
4. Actions in HMI
5. Team management
6. Team communication
7. Individual work practise
8. Available time for the tasks
9. Number of tasks/information load
10. Masking
11. Degree of severity

Summary, Collaboration with NRC

- Experiments tailor-made to support HRA data needs
- Exchanging staff with INEEL as part of cooperation
  - Curtis Smith in Halden Sep 2003 – July 2004
- Integrating efforts with NRC HERA development
  - HERA training in Idaho March 2004
  - Design of studies to support HERA development
- Two Halden process experts to Chattanooga, two weeks training to learn more about U.S. plants, April 19-30 2004 ←

Summary

- Simulator experiments can inform HRA
- Data for post-initiating event operator actions
- Improved understanding of human performance
- Reduced uncertainty for HRA

OFFICE COPY

MATERIAL on HRA SUBCOMMITTEE MEETING April 22, 2004

JCN W6994
Draft Letter Report

Good Practices for Implementing Human Reliability Analysis (HRA)

Date: April 6, 2004

Prepared by
Alan Kolaczkowski and John Forester

Sandia National Laboratories
Albuquerque, NM 87185

USNRC Project Manager: Erasmia Lois

Prepared for
Probabilistic Risk Analysis Branch
Division of Risk Analysis and Applications
Methods Group
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Table of Contents

Good Practices for Implementing Human Reliability Analysis (HRA)

1. INTRODUCTION

1.1 Background

In accordance with its policy statement [1] on the use of probabilistic risk assessment (PRA), during the last decade the NRC has been increasingly using PRA technology in "all regulatory matters to the extent supported by the state of the art in PRA methods and data." Examples of risk informed initiatives are: undertaking risk-informed rulemaking activities such as risk-informing 10CFR Part 50[2], generating a risk-informed framework for supporting licensee requests for changes to a plant's licensing basis (Reg Guide 1.174),[3] risk-informing the reactor oversight process, performing risk studies (e.g., for steam generator tube rupture (SGTR), and fire events), and evaluating the significance of events. In addition, the NRC is using PRA in the development of an infrastructure to licence new reactors.

Given the increasing importance of the role of PRA in regulatory decision making, it is crucial that decision makers have confidence in the results produced by PRAs. To support this, the NRC has issued Regulatory Guide 1.200[4] that describes an acceptable approach for determining the technical adequacy of PRA results for risk informed activity. Reg Guide 1.200[4] reflects and endorses guidance provided by standards produced by societies and industry organizations. It currently addresses the American Society of Mechanical Engineers (ASME) Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications[5] which was developed for a full power, internal events (excluding fire) Level 1 PRA and a limited Level 2 PRA, and the Probabilistic Risk Assessment Peer Review Process Guidance (NEI-00-02).[6]

The level of detail provided in the ASME Standard[5] and NEI-00-02[6] is at a high level, addressing what to do, but not how to do it., Consequently, there may be several approaches to address certain analytical elements, which though they may meet the standards, may do so by making different assumptions and approximations, and, therefore, produce different results. This is particularly true of human reliability analysis (HRA) (see section 1.2 for a discussion of HRA). Therefore, the guidance provided by these documents is not sufficient to address the detailed HRA quality issues needed to be considered in regulatory decision making. For example, in section A.8, Modeling of Human Performance, in Standard Review Plan 19,[7] the NRC staff is required to determine if "the modeling of human performance is appropriate." While the ASME Standard[5] and NEI-00-02[6] can address whether the HRA addresses the right issues, they do not give guidance on how they are addressed. Therefore, in order to support the review of human performance issues in the context of PRAs, the NRC is developing this guidance for performing and reviewing HRAs, as a document supporting Reg Guide 1.200[4]. The guidance is being developed in two phases. The first phase is the development of this "HRA Good Practices" document which has been prepared on the basis of the NRC experience and lessons learned from developing HRA methods (e.g., THERP,[8] SLIM,[9] and ATHEANA[10]), performing HRAs (e.g., NUREG-1150[11] studies, and reviewing HRAs (in particular the individual plant examinations [IPEs]). The second phase is a review and evaluation of existing HRA approaches for their capability to meet the good practices when employed to address different regulatory applications.

This volume describes the NRC staff views regarding good practices of an HRA as implemented within a broader PRA. The volume is written in the context of a risk assessment for commercial nuclear power plant (NPP) operations occurring nominally at full power. However, it is likely that many of the good practices will also be applicable to low power and shutdown operations. Similarly, the volume is purposely aimed for applications involving internal initiating events but should generally be appropriate for external initiating events. Additionally, elements of this volume may be of benefit in examining human actions related to nuclear materials and safeguard types of applications.

As with any evolving technology, both PRA and the implementation of HRA within the PRA framework are continuing to improve. Hence, what is good practice today may be somewhat inferior or outdated tomorrow. Much of what is in this volume will always constitute good practice; some of it may be subject to newer technology, methods, and tools. For this reason, this volume must be considered a snapshot of good practices in HRA circa 2004.

With the expectation that PRA will continue to be used in the commercial nuclear industry in assessing current operating risks, in estimating changes in risk as a result of temporary and permanent plant changes to existing plants, and as an adjunct to the design process of newer generation plants, it is important that HRA practitioners perform human reliability analyses in accordance with good practices and that reviewers recognize the implementation of good practices (or failure to do so) in these analyses.

1.2 HRA in the Context of PRA

Human reliability analysis in the PRA context is that discipline that identifies and provides probabilities for the human failure events that can negatively impact normal or emergency plant operations. The human failure events modeled in PRAs that are associated with normal plant operation include: 1) events that leave equipment in an unrevealed, unavailable state, such as miscalibration of a level sensor, 2) those that induce an initiating event, such as a human-caused loss of feedwater (typically captured by the initiating event frequency), or 3) those modeled as human events contributing to an initiating event, such as a total loss of service water (e.g., failing to backup the start of service water train B upon loss of train A). The human failure events modeled in PRAs associated with emergency plant operation include events that, if not performed, do not allow the desired function to be achieved, such as failing to initiate feed and bleed. Quantification of the probabilities of the human failure events is based on plant and accident specific conditions, where applicable, including any dependencies among actions and conditions.

This volume provides HRA good practices that when implemented will result in determining the impacts of human actions as *realistically as necessary* in an assessment of risk. Note the emphasis on realistic as necessary rather than as realistic as possible. For example, depending on the purpose for which the PRA is to be used, a conservative treatment of human performance may be sufficient to address a PRA application; more realism may not be necessary and could be a waste of resources. However, a conservative approach may not be sufficient when used as the basis for not needing to further investigate the issue at hand. Such an approach could potentially constrain the capability of identifying weaknesses in plant operations and plant practices related to the particular human actions credited in the PRA.

Recognizing that the volume will be used to guide a wide variety of applications, it is not intended that all the practices be met for any specific PRA application; in fact, some may not be applicable or necessary. A practitioner or reviewer should determine the applicable good practices for the PRA application and perform or review the HRA accordingly.

1.3 Purpose

This volume serves as a reference guide of good practices in HRA. By good practices we mean those processes and individual analysis tasks and judgments that would be expected of a HRA (considering current knowledge and state-of-the-art) in order for the HRA results to sufficiently represent the anticipated operator performance when making risk-informed decisions. The document is principally focused on the process for performing HRA and does not, for instance, specifically address HRA data or details of specific quantification approaches. As such, it is written in a way that links the prescribed good practices to requirements in the ASME Standard[5] and particularly the HRA section of that document (although nearly all other sections of the standard also have some parallel requirements with regard to operator actions such as in the accident sequence analysis, success criteria, systems analysis, and large early release frequency (LERF) analysis sections).

With this in mind, this volume has at least two primary uses.

1. It provides guidance for performing a good HRA (whether for the first time or when analyzing a change to current plant practices) when implementing the ASME Standard,[5] and focuses on the attributes of a good HRA regardless of the specific methods or tools that are used. The guidance is specifically for HRAs for full power, reactor, and internal events applications although most of the guidance may prove to be useful for other applications (e.g., external events, other operating modes...). It does not endorse nor is it meant to suggest that a specific method or tool be used since many exist, and all have strengths and limitations regarding their use and applicability. Nevertheless, the good practices come from those advocated in such sources as the ASME Standard[5], THERP[8], ASEP[12], SHARP1[13], SPAR-H Method[14], and ATHEANA[10] for example, as well as the experiences of the authors and reviewers of this volume.

2. It supports the review of HRAs in assessing the quality of the analyses. In this regard, the practices of a good HRA are provided which should be useful in formulating questions about and measuring the "goodness" of a HRA. Its purpose is not to explicitly provide questions a reviewer should ask, but rather to provide the technical basis for developing questions or a standard review plan for the staff's review of HRA.

2. OVERVIEW OF GOOD PRACTICES FOR HRA

2.1 Scope of HRA Good Practices Guidance

The purpose of this document on good practices for implementing HRA is to ensure some level of consistency and quality in HRA analyses and their review. In order to achieve such consistency and quality, the HRA good practices in this document are directed at specific HRA tasks or activities.

The performance of HRA typically involves several tasks or activities. Some of these tasks are dependent on the HRA method or quantification approach that is used. Because this HRA good practices document does not endorse or specify the use of specific HRA methods or quantification approaches, most of the guidance in this document is directed at the process for performing HRA. However, this document does provide some non-method-specific good practices with respect to HRA quantification.

As stated in Section 1, the ASME Standard[5] already addresses these HRA tasks or activities at a high level. In the NRC's judgement, the more detailed guidance given in this document on HRA good practices is necessary to achieving acceptable consistency and quality in HRA.

2.2 HRA Good Practices and the State-of-the-Art in HRA

The HRA good practices given in this document are based in part on past experience in performing and reviewing HRAs, including that used to support the IPEs, but also reflect current perspectives on the issues that impact human performance that were gained from developmental projects such as ATHEANA[10]. Consistent with the state of the art in PRAs, it is recommended that future HRA/PRAs attempt to identify and model potentially important EOCs. This report provides some guidance for identifying characteristics of situations that can facilitate errors of commission. As stated above, these good practices apply to the use of all HRA methods and approaches.

2.3 Summary and Organization of HRA Good Practices Guidance

The good practices are presented in a logical analysis approach and linked to the requirements of the ASME Standard.[5] Like the standard, this document specifically addresses pre-initiator (i.e., normal operations) and post-initiator (i.e., emergency operations) human actions since it is assumed that as typical of most PRAs, human actions that cause or contribute to initiating events are already accounted for quantitatively in many initiating event frequencies. Further understanding of specific causes of the initiators is typically not required. It is noted that for support system initiators and other initiators such as those human-induced initiators that may be modeled for other modes (e.g.,shutdown), corresponding initiator fault tree models may specifically include human failure events (HFEs) that have characteristics of either pre- or post-initiating event HFEs. The techniques used to analyze these HFEs are therefore covered by this document and should be followed. For example, see HLR-IE-C high level requirement in the ASME Standard[5] and such supporting requirements as IE-C9 concerning the modeling of recovery actions in an initiator fault tree, and IE-C12 concerning procedural influences on the interfacing system loss of coolant accident (ISLOCA) frequency.

While this document is written in a serial fashion, in practice, it is often desirable to perform or review an HRA in a more holistic manner and address multiple steps of the HRA process simultaneously to achieve greater resource efficiency.

Table 2-1 provides brief summaries of the good practices that are discussed in subsequent sections of this document (to be provided later).

Table 2-1 Summary of Good Practices

[Table 2-1 to be inserted later]

3. HRA TEAM FORMATION AND OVERALL GUIDANCE

If human actions are going to be included realistically in the PRA, the modeling of human interactions must consider each action evaluated in the context of a complete accident scenario or sequence of events. To do this, HRA has evolved from the days when PRA analysts provided the human events of interest to a HRA specialist who then assigned human error probabilities (HEPs) to the human events, often in isolation. Such a process is no longer considered good practice. Understanding an accident sequence context is a complex, multi-faceted process. The interaction of plant hardware response and the response of plant operators must be investigated and modeled accordingly. Such characteristics as the following need to be understood and reflected, as necessary, in the model of a specific human action or group of actions:

- plant behavior and conditions,

- timing of events and the occurrence of human action cues,

- the parameter indications used by the operators and changes in those parameters as the scenario proceeds,

- the time available and locations necessary to take the human actions,

- the equipment available for use by the operators based on the sequence ,

- the environmental conditions under which the decision to act must be made and the actual response must be performed,

- the degree of training guidance and procedure applicability, among many other characteristics.

Much of the guidance in this volume is aimed at good practices for understanding the context associated with each modeled human action, and how that context affects both the definition of human failure events and an assessment of their probabilities.

This emphasis on the need to adequately understand and address context in order to more realistically address human performance is based on advances in our understanding of the factors that can influence human performance. These advances come from recent reviews of operational events involving serious accidents (e.g., ATHEANA[10]) and from other international efforts and recent research in the cognitive sciences that together have provided a clearer picture of the ways in which various factors and situations can interact to influence the occurrence of inappropriate human actions (e.g., Reason[15], Woods[16], Endsley[17]...). Improvements have been made for how to address the broad range of potential influences on human performance, for both the identification of the human actions to be modeled in the PRA as well as what to consider during screening and detailed quantification of the actions. The guidance in this volume provides good practices that reflect these improvements and ensures the proper treatment of context in performing a reasonably realistic HRA.

Hence, the modeling of human actions in the PRA should involve an integrated effort among PRA modelers, HRA and human factors practitioners, thermal-hydraulic analysts, operations and maintenance personnel, and sometimes other disciplines depending on the accident sequence (e.g., structural engineers such as if the timing of an action is dependent on when and how the containment might fail). Each discipline provides a portion of the context knowledge. When the context is sufficiently understood, only then can human failure events be realistically modeled and quantified. In addition, as good practice in HRA, it is encouraged that there be the use of walkdowns of areas where the action needs to take place, talk-throughs of the scenarios and actions of interest with plant operators or maintenance personnel, field observations, and at least for the more important actions, simulations of the human actions to be credited. Finally, the HRA should be performed consistently for both core damage prevention/mitigation and large early release prevention/mitigation since both measures are considered in making risk-informed decisions as addressed in Regulatory Guide 1.174[3].

Therefore, in summary and as the first measure of a good HRA, it should be clear that an HRA assessment has utilized an integrated team and tools as summarized in Table 3-1 to the extent necessary and practical for the PRA application and the specific issue being addressed. This is an important aspect that should lead to HRA results that are credible.

Table 3-1 Overall HRA Good Practices

1. The HRA is an integral part of the PRA (not performed as an isolated task in the PRA process) whereby the inputs from the following types of disciplines are used together to define the PRA structure including which human events need to be modeled, how they are defined and modeled in the PRA, and the considerations used to quantify the associated HEPs: • PRA modelers • HRA practitioners • Thermal-hydraulic analysts • Operations and maintenance personnel • Other disciplines (e.g., structural engineers, system engineers...) as necessary
2. Besides the review of plant documents, the HRA is performed using the insights gained from the following to confirm judgments and assumptions made from the document review: • Walkdowns of areas where decisions and actions are to take place • Talk-throughs of scenarios and actions of interest • Field observations • Simulator exercises
3. As part of the integrated effort, the HRA is performed consistently for both core damage and large early release outcomes, since both are equally important in risk-informed applications.

4. PRE-INITIATOR HRA

The ASME Standard[5] separates its requirements into two broad classifications; those that address the modeling of failures of pre-initiator human actions and those that address the modeling of failures of post-initiator human actions. This section provides good practices for implementing the requirements for addressing pre-initiator human failure events in a PRA.

Pre-initiator human failure events are events that represent the impact of human failures committed during actions performed prior to the initiation of an accident sequence (e.g., during test or maintenance or the use of calibration procedures). They are important to model because plant personnel can make the equipment needed to mitigate a particular accident sequence unavailable, thus reducing the overall capability to respond to the initiating event. Hence, depending on the issue being addressed, this impact may need to be included in a PRA if a realistic assessment of risk is required.

The following good practices are categorized under four major analysis activities for doing pre-initiator HRA. These analysis activities are:

1. Identifying activities that have the potential to result in pre-initiator human failures
2. Screening out the activities for which human failures do not need to be modeled
3. Modeling specific human failure events (HFEs) corresponding to the unscreened activities
4. Quantifying the corresponding human error probabilities (HEPs) for the specific HFEs.

4.1 Identifying potential pre-initiator human failures

4.1.1 OBJECTIVE: To identify from routine plant actions, those pre-initiator actions whose failure to perform correctly could result in the human-induced unavailability of PRA-modeled equipment that is credited in the PRA accident sequences. This is important since these actions represent other potential modes of unavailability of the credited equipment (besides the equipment simply failing to start or other failure modes in the PRA) that contribute to overall plant risk. Note that not all the identified actions will be modeled since some may be screened from further analysis in the following analysis activity (screening). The following provides good practices for identifying potential pre-initiator human failures while implementing the related Standard requirements.

4.1.2 CORRESPONDING ASME STANDARD REQUIREMENTS:

The Standard calls for a systematic process to be used to identify routine activities that if not completed correctly, may impact the availability of equipment. There are multiple supporting requirements in the Standard that address the need to consider test and maintenance activities, calibration activities, and actions that could affect multiple equipment.

4.1.3 GOOD PRACTICES:

4.1.3.1 Good Practice #1:

The HRA process should include a review of the following:

- All routine (scheduled) test and maintenance as well as calibration procedures that affect equipment to be credited in the PRA (for core damage frequency (CDF) and LERF) should be identified and reviewed.

- Actions specified in the above procedures that realign equipment outside their normal operation or standby status, or otherwise could detrimentally affect the functionality of credited equipment if not performed correctly (e.g., miscalibration) should be identified.

- "Affected" equipment should include (if routinely acted on and credited in the PRA):

    - the primary systems, structures, and components (SSCs) (e.g., emergency core cooling systems' components, containment cooling systems' components...),

    - support systems (e.g., power, air, cooling water...),

    - cascading effects among the equipment (e.g., if the realignment of an equipment item in one procedure such as an air-operated valve would implicitly require the subsequent realignment of another equipment item such as isolation of an air line that would then disable a portion of the air system), and

    - instrumentation (e.g., indicators, alarms, sensors, logic devices...) and controls (e.g., hand switches...) that (a) affect automatic operation of the above primary and support system equipment and/or (b) *at least singularly* are relied upon (as opposed to multiple, redundant items) to credit post-initiator human actions to be included in the model (e.g., a single subcooling indication relied upon to meet an emergency core cooling termination criteria which if miscalibrated could induce failure of the appropriate post-initiator operator action).

4.1.3.2 Good Practice #2:

The identification process should identify pre-initiator human actions even if they may be potentially covered by the affected equipment failure data (see section 4.1.4 for additional information).

4.1.3.3 Good Practice #3:

If applicable and credited in the analysis, the identification process should address other operational modes and routine actions affecting barriers and other structures such as fire doors, block walls, drains, seismic restraints, etc.

4.1.3.4 Good Practice #4:

The identification process needs to include possible pre-initiator actions *at least within each system* where redundant or multiple diverse equipment can be affected by (a) a single act (e.g., misalignment of a valve affecting multiple system trains or even multiple systems) or (b) through a common failure with similar multiple acts (e.g., mis-calibrating multiple sensors due to incorrect implementation of the same calibration procedure or use of the same mis-calibrated standard). For the latter case, the analyst should not duplicate that already covered under the common cause failure modeling of the equipment, but should include consideration of possible commonalities such as:

- same crew, same shift performing the actions (common "who" mechanism),

- common incorrect calibration source (common "what" mechanism),

- common incorrect tool, process, or procedure/training, or inadequate material (e.g., wrong grease) (common "what/how" mechanisms), and

- close proximity in time and/or space/location of similar multiple acts (common "when/where" mechanisms).

The more these commonalities co-exist, the more the identification process should consider the act as a potentially important pre-initiator action to be included.

4.1.4 POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:

Besides the obvious issues associated with incompleteness and inaccuracy and thereby potentially missing a risk-significant pre-initiator action, the following observations are noted.

- Missing or unnecessarily including an action is often not a serious mistake (i.e., would not significantly affect the overall risk) unless the action can affect multiple equipment items. This is because with common nuclear plant practices and designs, typically those actions that could affect multiple trains of equipment tend to be the more significant pre-initiator human failures. Those affecting just one equipment item are usually not important unless the equipment item has a high operating reliability (e.g., failure to start or run is in the 1E-4 or lower probability range) and so the pre-initiator failure probability could be a significant contributor to the unavailability of the equipment.

- One should include the possible failures associated with routine test and maintenance or calibration procedures that could affect critical instrumentation, diagnostic devices, or specific items like pushbuttons, etc. that have no redundancy or diverse means of function. While typically such situations do not exist in nuclear power plants, changes to the plant could conceivably and unintentionally create such a situation. Affecting the operator's ability to take the desired action is similar, functionally, to affecting the equipment item itself which is to be activated. Hence, it at least should be ensured that such situations, from a possible pre-initiator perspective, do not exist or if they do, they are addressed.

- In practice, it is best to include pre-initiator actions even if the associated failure may already be included in the failure data for the affected equipment item (e.g., in the failure-to-start data). This is because it is often hard to determine if the failure data bases include such human failures since data bases are typically insufficiently documented to know if the potential pre-initiator failure is already included. Generally, unless the failure can affect multiple equipment, such failings tend to not be important since missing them or double-counting them tend not to be serious PRA problems. Potential double-counting is the most conservative thing to do, and yet typically not a serious over-estimation of the failure's significance. In addition, including all identified pre-initiators gives analysts the opportunity to identify potentially problematic actions such as those with procedural or training problems, those that do not require appropriate checks, etc.

- If applicable, one should include the possible failures associated with routine test and maintenance or calibration procedures that could affect equipment critical to external events such as fire barriers (e.g., opening a fire door and failing to restore its closed position), seismic restraints, floor drains and barriers, wind barriers, etc. While typically such situations do not exist in nuclear power plants since such equipment items often do not have routine test, maintenance, or calibration activities that would adversely affect their function, changes to the plant or plant practices, for instance, could conceivably and unintentionally create such a situation. To the extent the analysis assumes the functionality of these normally highly reliable devices, pre-initiator failures that could affect these devices could be potentially important. Hence, it at least should be ensured that such situations, from a possible pre-initiator perspective, do not exist or if they do, they are addressed.

- Considering the potential importance of acts that affect multiple equipment, the identification process should search for acts that affect multiple equipment items *at least within a system* (e.g., auxiliary feedwater system, reactor core injection system...) as this represents the current state of the art in PRA. A search across multiple systems (e.g., auxiliary feedwater and high pressure injection) is an expansion of the current state of the art and should not be expected except for those cases where the same instrumentation or equipment (e.g., pressure signals, same tank level equipment) activates or affects multiple systems.

4.2 Screening those activities for which human failure events do not need to be modeled

4.2.1 OBJECTIVE: To screen out those activities for which associated failures do not need to be analyzed because they should be probabilistically unimportant. The screening process, though largely qualitative, is based on the belief that certain design or operational practices make some pre-initiator failures sufficiently unlikely that they will not be risk significant failures and therefore do not need to be modeled. The following provides good practices for screening out pre-initiator human actions and associated human failures while implementing the related Standard requirements.

4.2.2 CORRESPONDING ASME STANDARD REQUIREMENTS:

The Standard addresses allowable screening of activities based on practices that limit the likelihood of errors in those activities. There are multiple supporting requirements in the Standard that address screening rules or criteria, as well as the requirement to not screen actions that could affect multiple equipment.

4.2.3 GOOD PRACTICES:

4.2.3.1 Good Practice #1:

A candidate pre-initiator action can be screened out (i.e., not to be modeled) if the nature of the associated action meets any of the following criteria and the reason for screening is documented (see exception under Good Practice #2 below):

- the affected equipment will receive an automatic realignment signal and it can respond (i.e., is not disabled) if demanded, or

- there is a valid post-maintenance/test functional check after the original manipulation which will reveal misalignment or incorrect status (e.g., faulty position, improper calibration), or

- following the original action(s), an independent second verification of equipment status using a written checklist that will verify incorrect status is performed, or

- a valid check, at least once per shift, of equipment status that will reveal misalignment or incorrect status, is used, or

- there is a compelling signal (e.g., annunciator or indication) of improper equipment status or inoperability in the control room, it is checked at least shiftly or daily, and realignment can be easily accomplished, or

- other criteria as long as it can be demonstrated that the resulting human error probabilities would be low compared with the failure probabilities (e.g., failure to open) of the equipment.

4.2.3.2 Good Practice #2:

Do not screen out those actions and possible pre-initiator failures that simultaneously affect multiple (redundant or diverse) equipment items (see Good Practice #4 under Section 4.1.3).

4.2.3.3 Good Practice #3 (application-specific):

For a specific PRA application and depending on the issue being addressed (e.g., examination of a specific procedure change), revisit the original PRA screening process to ensure issue-relevant human actions have not been deleted from the PRA prior to its use to assess the new issue.

4.2.4 POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:

Besides the obvious issues associated with inappropriate screening and thereby potentially missing a risk-significant pre-initiator action, the following observations are noted.

- Generally, screening out pre-initiator failures (i.e., don't have to be modeled) is acceptable based on experience with past PRAs and the types of pre-initiator failures that are typically found to be unimportant. This is done to simplify the model and not expend resources addressing unimportant pre-initiator actions. It should be clear that an appropriate level of investigation has been performed to ensure the above criteria have been met and if these or other criteria are used, their justification is documented for outside review. It is advisable that a record of all screened actions be kept for later reference when performing specific applications (see Good Practice #3). When in doubt, it is recommended the pre-initiator action not be screened out but the corresponding failure modeled in the PRA for further analysis.

- Since pre-initiator actions and related failures affecting multiple equipment items can sometimes be risk important, none of these should be screened out but should be modeled and examined in more detail in the PRA because of the potential consequences of the failure.

- There can be a tendency to want to use an existing PRA model to address issues such as changes to the plant, without spending the appropriate time to revisit some of the underlying assumptions and modeling choices made to create the original PRA. Such a review should be done to see if these assumptions and choices still apply for the issue being addressed. In this case, some pre-initiator failures may not have been included in the original PRA (i.e., screened out) that in light of the new issue being addressed, should now be included in the model (i.e., could be important for addressing the issue). Hence it is good practice to implement a process that ensures that some of the formerly screened out pre-initiator failures do not have to be added back-in to the model in order to appropriately address the issue.

4.3 Modeling specific human failure events (HFEs) corresponding to the human failures

4.3.1 OBJECTIVE: To define how the specific pre-initiator HFE is to be modeled in the PRA to accurately represent the failure of each action identified and not screened out from the above analysis activities. The HFE needs to be linked to the affected equipment (single or multiple) and needs to appropriately define the failure mode of that equipment that makes the equipment unavailable. The following provides good practices for modeling pre-initiator human failure events while implementing the related Standard requirements.

4.3.2 CORRESPONDING ASME STANDARD REQUIREMENTS:

The Standard calls for the modeling of pre-initiator HFEs based on the impact of the failure in the PRA. There are multiple supporting requirements in the Standard that address the modeling level of detail for each HFE and the modes of failure to be considered.

4.3.3 GOOD PRACTICES:

4.3.3.1 <u>Good Practice #1:</u>

Define each specific pre-initiator HFE to be modeled in the PRA as a basic event that describes the human-induced failure mode and is located in the model such that it is linked to the unavailability of the affected component, train, system, or overall function (i.e., level of modeling) depending on the effect(s) of the HFE (e.g., a single valve will not close, a train will be isolated, the automatic start signal for an entire system will be disabled). The following attributes, as a minimum, should be used to define the pre-initiator failure level properly in the PRA:

- the nature of the manipulation affects a whole train, system, etc. so it makes more sense to define the HFE at that level,

- multiple individual acts affecting multiple equipment (e.g., different components) can be combined as a single pre-initiator HFE affecting a higher level of equipment resolution (e.g., the train containing the different components) as long as (a) the acts and effects are related, (b) how the single HFE will be quantified (i.e., the performance-shaping factors that would affect quantification as discussed later) is not significantly different or will be conservatively bounding than if the individual acts were to be modeled and quantified separately, and (c) there are no potential commonalities/dependencies with other pre-initiator acts elsewhere in the model so that potential common failures among similar individual acts might be missed (e.g., miscalibration of multiple signal channels), and

- consideration of the level of detail already modeled in the PRA (e.g., train, system) for failures of the associated equipment (less important factor).

The failure modes (fail to close, fail to start, etc.) should be a direct result of considering the equipment affected and the effects of the human-induced failure (refer to all the Good Practices under Section 4.1.3) and stem from failure to restore equipment and/or otherwise correct the adverse effect (such as miscalibration) so that the equipment is again operable. The failure modes should clearly describe the HFE effect to ensure proper interpretation of the HFE in the model (e.g., only two of three redundant sensors need to be disabled to make the actuation signal unavailable, and not all three sensors have to be disabled).

As an aid to ensure appropriate modeling, it is recommended practice (but not necessary) that the pre-initiator failure be placed in close proximity, in the PRA model, to the equipment affected by the human failure. In this way, a quick comparison can be made between the equipment failure and the pre-initiator human failure to ensure they are consistent.

4.3.4 POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:

The precise definition of the pre-initiator basic events and their placement in the model (from both a logic and failure mode standpoints) ultimately define how the model addresses the effects of the human failures. This needs to be done accurately if the model is going to logically represent the real effects of each human failure and if the corresponding HFE is going to be correctly quantified (as discussed later).

4.4 Quantifying the corresponding human error probabilities (HEPs) for the specific HFEs

4.4.1 OBJECTIVE: To address how the human error probabilities (HEPs) for the modeled HFEs from the previous analysis activity are to be quantified. This section provides good practices guidance on an attribute or criteria level and does not endorse a specific tool or technique (although THERP[3] or its ASEP[4] simplification are among those often used). Ultimately, it is these probabilities along with the other equipment failure and post-initiator human error probabilities as well as initiating event frequencies that are all combined to determine such risk metrics as CDF, LERF, △CDF, △LERF, etc. as addressed in Regulatory Guide 1.174[11]. The following provides good practices for quantifying pre-initiator human failure events while implementing the related Standard requirements.

4.4.2 CORRESPONDING ASME STANDARD REQUIREMENTS:

The Standard calls for a systematic process for assessing the pre-initiator HEPs that addresses plant-specific and activity-specific influences. There are multiple supporting requirements in the Standard that address many factors associated with quantifying the HEPs. These include when screening vs. detailed estimates are appropriate, performance-shaping factors considered in the evaluations, treatment of recovery, consideration of dependencies among HFEs, uncertainty, and reasonableness of the HRA results.

4.4.3 GOOD PRACTICES:

4.4.3.1 Good Practice #1:

The use of screening-level human error probability (HEP) estimates is virtually necessary during the early stages of PRA development and quantification. This is acceptable (and almost necessary since not all the potential dependencies among human events can be pre-known) provided (a) it is clear that the individual values used are over-estimations of the probabilities if detailed assessments were to be performed AND (b) dependencies among multiple human failure events appearing in an accident sequence are conservatively accounted for. These screening values should be set so as to be able to make the PRA quantification process more efficient (by not having to perform detailed analysis on every human failure event), but not so low that later detailed analysis would actually result in higher HEPs. The screening estimates should consider both individual HEPs and the potential for multiple and possibly dependent human failure events for a given accident sequence (scenario). To meet these conditions, it is recommended that (unless a more detailed assessment is performed of the individual or combination events to justify lower values):

- no individual pre-initiator HEP screening value should be lower than 1E-2 (typical of highest pre-initiator values in PRAs), and

- multiple HEPs in the same sequence should not have a collective value lower than 5E-3 (accounts for a 0.5 high dependency factor) at this stage.

4.4.3.2 Good Practice #2:

As needed for the issue being addressed to produce a more realistic assessment of risk, detailed assessments (not just screening estimates) of at least the significant human failure event contributors should be performed. The PRA analyst can define the significant contributors by use of typical PRA criteria (not addressed here) such as importance measure thresholds as well as other qualitative and quantitative considerations. While the use of screening-level values (supposedly purposely conservative) may, at first, seem to be a "safe" analysis process, it can have negative impacts. Screening values can focus the risk on inappropriate human actions or related accident sequences and equipment failures because of the intentionally high HEPs. Such incorrect conclusions need to be avoided by ensuring a sufficient set of more realistic, detailed HEPs are included in the model.

4.4.3.3 Good Practice #3 (application-specific):

For a specific PRA application and depending on the issue being addressed (e.g., examination of a specific procedure change), revisit the use of screening vs. detail-assessed HEPs to ensure issue-relevant human actions have not been prematurely deleted from the PRA or there is an inappropriate use of screening vs. detailed values to properly assess the issue and the corresponding risk.

4.4.3.4 Good Practice #4:

HEP assessments should account for the most relevant plant-specific and activity-specific performance-shaping factors in the analysis of each pre-initiator HFE. There is not one consensus list of appropriate contextual factors (e.g., plant conditions, PSFs, activity characteristics, etc.) to be considered in the evaluation of the pre-initiator HEPs. Additionally, for a specific action, what factors are most relevant may be different (e.g., perhaps one act is time-sensitive because it is done in a high radiation area while another is most affected by the complexity of steps with many opportunities to make undetected mistakes). It should be qualitatively apparent that the factors seemingly most relevant to the act (based on an understanding of the act) have been considered in the corresponding HEP estimate.

Factors that are typically important to address because they tend to be variable and not almost always optimal based on typical nuclear plant practices, include:

- whether written work plans, job briefs, and related procedures (positive influences tending to lower the HEP), or verbal guidance and/or memory (more negative influences tending to raise the HEP) are used, as well as the quality of the information (e.g., look for ambiguities, incompleteness, inconsistencies, etc. that are negative influences and thus tend to raise the HEP),

- complexity (e.g., multiple and/or repetitive steps that are hard to track, use (or not) of checklists, several variables involved and calculations required...), and

- ergonomic issues (e.g., layout, available information [instruments, alarms, computer readouts, etc.], labeling, readability, highly physical...).

Other factors that tend to not be as important either because of typical nuclear plant practices or because the factors are typically less relevant include (it should still be ensured that the typical practice or irrelevancy is not compromised):

- skill level/experience/training of crew (typically adequate in nuclear plants for the jobs each crew member is to perform),

- stress level (not usually relevant in pre-initiator failures unless special situations such as potential personal harm, the need for fast sequential responses, etc. play a role),

- environmental factors such as temperature, humidity, radiation, noise, lighting, etc. (typically the environment is sufficiently benign except for special circumstances such as a high radiation environment and thus the desire to hurry the actions), and

- availability of time (not usually a strong factor in pre-initiator failures).

If the large majority of these factors affect the human performance negatively or if even just one or two is an overwhelming negative influence, the HEP will tend to be higher (e.g., 0.01 to 0.1 or even higher, not accounting for recovery addressed under Good Practice #5 below). Conversely, mostly positive influences should yield lower HEPs (e.g., <1E-3, with additional recovery factors still to be applied as addressed under Good Practice #5 below).

4.4.3.5 Good Practice #5:

Applicable recoveries applied to the HEP evaluations for the HFEs being analyzed should be used (multiple recoveries may be acceptable) where appropriate, but any dependencies among the initial failure and the recoveries, and among the recoveries themselves, must be considered (see Good Practice #6 below). Typical considerations in applying recovery include:

- post-maintenance or post-calibration tests are required and performed by procedure,

- independent verification, using a written check-off list, which verifies component status following maintenance/testing/calibration is used, and its practice has been verified by walk-throughs and examination of plant experience,

- the original performer, using a written check-off list, makes a separate check of component status at a later time,

- work shift or daily checks are performed of component status, using a written check-off list,

- there is a compelling feedback (e.g., alarm) that will enhance the original failure being detected and can be quickly recovered, or

- combinations of the above.

The more of these are applicable for a given pre-initiator HFE, the more the situation tends to increase the recovery potential (i.e., decrease the HEP) since each recovery, to the extent they are independent, result in a multiplier (e.g., 0.1) on the original HEP estimate thereby reducing its overall value.

Basic HEPs for pre-initiator HFEs for nuclear plant applications (including recovery) are typically expected in the 0.01 (among the highest) to 0.0001 range. Any values below the 0.0001 to 0.00001 range should be considered suspect unless justified.

4.4.3.6 Good Practice #6:

Dependencies among the pre-initiator HFEs and hence the corresponding HEPs in an accident sequence should be quantitatively accounted for in the PRA model. This is particularly important so that combined probabilities are not inadvertently too optimistic, resulting in the inappropriate decrease in the risk significance of human actions and related accident sequences and equipment failures. In the extreme, this could result in the inappropriate screening out of accident sequences from the model because the combined probability of occurrence of the events making up an accident sequence drops below a threshold value used in the PRA to drop sequences from the final risk results.

To address these dependencies, usually a level or degree of dependence among the HFEs in an accident sequence is determined, at first qualitatively (e.g., low, high, complete), and then combined HEPs are assessed accordingly. Once the first HEP has been estimated, subsequent quantitative factors for dependent human failures or recoveries of the original failure are typically expected to be:

- 0.01 to 0.1 for low dependence
- 0.1 to 0.5 for high dependence
- >0.5 for very high or 1.0 for complete dependence

Note that specific tools/techniques may use somewhat different probabilities than provided here based on specific considerations.

In establishing the level of dependence, Good Practice #4 under Section 4.1.3 addresses typical commonalities that tend to make HEPs more dependent (i.e., an HFE is not independent of another HFE and so once the first human failure occurs, there is a high likelihood that a similar second or third, etc. human failure will also occur such as the failure to restore the lineup of one train of equipment after a test and then failing to similarly restore the second train of equipment after a similar test). Good Practice #5 just above addresses recovery characteristics that tend to break-up these commonalities because they "recover" any initial error, making the individual HFEs more independent. The more the types of commonalities addressed under Good Practice #4 under Section 4.1.3 exist and the less corresponding recoveries under Good Practice #5 above exist, the higher should be the assessed level of dependence among the HFEs. To the extent the converse is true, low or even no dependence should be assessed.

4.4.3.7 Good Practice #7:

Point estimates should be mean values for each HEP (excluding screening HEPs) and an assessment of the uncertainty in the mean values should be performed at least for the dominant HEPs to the extent that these uncertainties need to be understood and addressed in order to make appropriate risk-related decisions. Assessments of uncertainty are typically performed by:

- assigning uncertainty distributions for the HEPs and propagating them thru the quantitative analysis of the entire PRA such as by a Monte Carlo technique, and/or

- performing sensitivity analyses that demonstrate the effects on the risk results for extreme estimates in the HEPs based on at least the expected uncertainty range about the mean value.

Note, in some cases, it may be sufficient to address the uncertainties by just qualitative arguments without the need to specifically quantify them (e.g., justifying why the HEP cannot be very uncertain or why a change in the HEP has little relevancy to the risk-related decision to be made).

In assessing the uncertainties, and particularly when assigning specific uncertainty distributions, the uncertainties should include (a) those epistemic uncertainties because of lack of knowledge of the true expected performance of the human for a given context and associated set of performance-shaping factors, and (b) consideration of the combined effect of the relevant aleatory (i.e., random) factors to the extent they are not specifically modeled in the PRA and to the extent that they could alter the context and performance-shaping factors for the HFE. For pre-initiator HFEs, there should be few or no aleatory factors worthy of consideration, since typically the procedure used, the environment experienced, etc. do not randomly change. But, for example, if different and significant crew experience levels are known to exist, it is random as to which crew will perform the pre-initiator act at any given time. In such a case, the mean should represent the average crew experience level and the uncertainty should reflect the possible range in those levels. Again, aleatory factors are typically not very relevant to pre-initiator HEPs and so typically are not important to address.

Whatever uncertainty distributions are used, the shape of the distributions (e.g., log-normal, normal, beta...) are typically unimportant to the overall risk results (i.e., the results are usually not sensitive to specific distributions). Further, typical uncertainties include values for the HEP that represent a factor of 10 to 100 between the lower bound value and the upper bound value that encompass the mean value.

4.4.3.8 Good Practice #8:

The pre-initiator HEPs (excluding the screening HEPs) should be reasonable from two standpoints:

- first and foremost, relative to each other (i.e., the probabilistic ranking of the failures when compared one to another), and

- in absolute terms (i.e., each HEP value) to the extent that the sensitivity of the risk-related decision is not important as to the absolute values for the HEPs.

This reasonableness should be checked based on consideration of actual plant experience and history, against other evaluations (such as for similar acts at other plants), and the qualitative understanding of the actions and the relevant contexts and performance-shaping factors under which the acts are performed. It is suggested that a rank-ordered list of the pre-initiator HFEs by probability be used as an aid for checking reasonableness. For example, simple, procedure-guided, independently checked actions should have lower HEPs than complex, memorized, not checked actions, all other factors being the same. Typical expectations of pre-initiator HEPs can be wide-spread (~0.01 to 0.0001) and depend particularly on the relevant contextual factors, applicable recoveries, and proper consideration of dependencies as discussed under many of the Good Practices covered above.

4.4.4 POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:

Besides the obvious concerns about inaccuracies in the HEP quantification and thus whether the HEPs "make sense", as well as the resulting potential misinformation about the dominant risk contributors if quantification is not done well, the following observations are noted.

- Screening is a useful and most often, necessary part of HRA so as to avoid the expenditure of resources on unimportant human events and accident sequences. The above guidance is aimed at allowing a level of useful screening without inadvertently and inappropriately allowing the analytical phenomenon of, for instance, multiplying three human events in the same sequence each at a screening value of 1E-2 to yield a 1E-6 combined probability, without checking for dependencies among the human events. In such a case some human failure events and combinations of events, or even whole accident sequences, may inappropriately screen out of the PRA model entirely because the accident sequence frequency drops below a model threshold. Hence some of the dominant individual or combination contributors may be missed. This is why the screening values both individually and for combined events should not be too low during the screening stage. Further, if screening values are left permanently assigned to some human failure events that should be assessed with more detail to obtain a more realistic assessment of risk (supposedly lowering the probability), the risk significance of these human failure events and related equipment failures are likely to be over-emphasized at the expense of improperly lessening the relative importance of other events and failures.

- It is important to be sure that dependencies among the various modeled HFEs including the associated recoveries, have been investigated (e.g., the same person as the originator of the action performing the recovery may be more prone to fail to detect the original failure than an independent checker). Treating HFEs and any corresponding recoveries as independent acts without checking for dependencies (thereby being able to multiply the individual HEPs) can inappropriately lessen the risk significance of those HFEs and related equipment failures in accident sequences. This can cause the inappropriate dropping out of accident sequences because the sequences quantitatively drop below a model threshold value as discussed above under screening. Proper consideration of the dependencies among the human actions in the model is necessary to reach the best possible evaluation of both the relative and absolute importance of the human events and related accident sequence equipment failures.

- The use of mean values and addressing uncertainties are a part of the Regulatory Guide 1.174[11] guidance and to the extent addressed therein, the HRA quantification needs to be consistent with that guidance when making risk-informed decisions.

- There can be a tendency for analysts to want to use an existing PRA model to address issues such as changes to the plant, without spending the appropriate time to revisit some of the underlying assumptions and modeling choices made to create the original PRA. A review should be done to see if these assumptions and choices still apply for the issue being addressed. In this case, some pre-initiator human failure events may be quantified in the original model using a set of screening estimates and detailed failure probabilities that may not be appropriate for the new issue being addressed. As an example, where higher screening values may have been acceptable for purposes of the original PRA, these supposedly conservative values may over-estimate the contribution of these human failure events for the issue being addressed. Further, the relative risk contribution of equipment and associated accident sequences with which the human failure events appear, may be artificially too high (and therefore other events too low) because of the screening values. Hence it is good practice to revisit the use of screening and detailed human failure event probabilities in order to appropriately address the issue.

5. POST-INITIATOR HRA

The ASME Standard[5] separates its requirements into two broad classifications; those that address the modeling of failures of pre-initiator human actions and those that address the modeling of failures of post-initiator human actions. This section provides good practices for implementing the requirements for addressing post-initiator human failure events (HFEs) in a PRA.

Post-initiator human failure events are events that represent the impact of human failures committed during actions performed in response to the initiation of an accident sequence (e.g., while following post-trip procedures or performing other recovery actions). They are important to model because humans can have a direct influence on the mitigation or exacerbation of undesired plant conditions after the initial plant upset. Hence, depending on the issue being addressed, this impact may need to be included in a PRA if a realistic assessment of risk is required.

The following good practices are categorized under four major analysis activities for doing post-initiator HRA. These analysis activities include:

1. Identifying potential post-initiator human failures
2. Modeling specific human failure events (HFEs) corresponding to the human failures
3. Quantifying the corresponding human error probabilities (HEPs) for the specific HFEs
4. Adding recovery actions to the PRA.

5.1 Identifying potential post-initiator human failures

5.1.1 OBJECTIVE: To identify the key human response actions that may need to be taken by the operators in response to a variety of possible accident sequence s and that will therefore need to be modeled in the PRA. This is important since failures associated with these actions (e.g., failure to start standby liquid control, failure to initiate feed and bleed, failure to properly control steam generator feed flow, failure to align containment/suppression pool cooling) are represented in the PRA such that in combination with equipment failures, are expected to lead to core damage and/or large early releases. Such failures contribute to the overall risk and thus a systematic process needs to be followed to identify these response actions. The following provides good practices for identifying post-initiator human failures while implementing the related Standard requirements.

5.1.2 CORRESPONDING ASME STANDARD REQUIREMENTS:

The Standard calls for a systematic review to identify operator responses required for each of the accident sequences. There are multiple supporting requirements in the Standard that address what to review as well as the types of actions to be included. Use of talk throughs and simulator observations are also addressed as part of the supporting requirements.

5.1.3 GOOD PRACTICES:

5.1.3.1 Good Practice #1:

Reviews of the following form the primary bases for identifying the post-initiator actions.

- Review plant-specific emergency operating procedures (EOPs), abnormal operating procedures (AOPs), annunciator procedures, system operating procedures, severe accident management guidelines (SAMGs), and other special procedures (e.g., fire emergency procedures) as appropriate. The review is done to identify ways operators are intended to interact with the plant equipment after an initiator as a function of the various conditions that can occur as defined by the development of the PRA accident sequences and equipment unavailabilities and failure modes. Particularly note where operator actions are called out in these procedures and under what plant conditions and indications (cues) such actions are carried out. It will also be useful at this time to examine whether there are any potential accident conditions under which the procedures might not match the situation as well as would be desired, e.g., potentially ambiguous decision points or incorrect guidance provided under some conditions. Information about such potential vulnerabilities will be useful later during quantification and may help identify actions that need to be modeled.

While not necessary at this stage of the analysis (probably more beneficial during the modeling and quantification phases, but could be started at this stage on a selective basis of likely importance), the results of the following additional reviews may add to the list of actions and/or help interpret how procedural actions should be defined based on how they are actually carried out.

- Review of training material including, where possible, talk-throughs or walkdowns of the actions with operations or training staff to ensure consistency with training policies and teachings, and to identify likely operator response tendencies for various conditions that may not be evident in the procedures (although it is not the intent to perform numerous or detailed talk-throughs, walkdowns, or simulations at this phase of the analysis - the use of these techniques is more relevant later under the HFE modeling and quantification phases). For example, operators may cite a reluctance to restart reactor coolant pumps in spite of the procedure direction based on their training and perceived adverse effects, or they may have a preference to use condensate as a BWR injection source before using lower pressure emergency core cooling system. These added "interpretations" of the procedures can help complete and/or clarify the identified actions and ensure that later modeling and quantification of the actions will reflect the "as-operated" plant.

- Observations of simulated accidents since these can provide valuable insights with regard to how the actions are actually carried out, by whom, and particularly how procedure steps are interpreted by plant crews especially where the procedure is ambiguous or leaves room for flexibility in the crew response (although it is not the intent to perform numerous or detailed talk-throughs, walkdowns, or simulations at this phase of the analysis - the use of these techniques is more relevant later under the HFE modeling and quantification phases). For example, through simulation it may be observed that a "single action" in the procedure (e.g., align recirculation) is actually carried out by a series of numerous and sequential individual actions (e.g., involving the use of many handswitches in a certain sequence). Again these observed "interpretations" of the procedures can help complete and/or clarify the identified actions and ensure that later modeling and quantification of the actions will reflect the "as-operated" plant.

5.1.3.2 Good Practice #2:

The review process should involve the following:

- Knowledge of the functions and associated systems and equipment to be modeled in the PRA for both CDF and LERF.

- Identifying whether the function is needed (e.g., injection) or undesired (e.g., stuck-open safety relief valve) recognizing these may vary with different initiators and sequences.

- Identifying the systems/equipment that can contribute to performing the function or cause the undesired condition including structures and barriers where appropriate (e.g., fire door, floor drains) especially for external event analyses.

- Identifying ways the equipment can functionally succeed (i.e., the success criteria) and fail.

- Based on the above, identifying ways the operators are (a) intended/required to interact with the equipment credited to perform the functions modeled for the accident sequences modeled in the PRA and/or (b) to respond to equipment and failure modes that can cause undesired conditions per the PRA. During the identification process, it is helpful to use action words such as actuate, initiate, isolate, terminate, control, change, etc. so that the desired actions are clear.

5.1.3.3 Good Practice #3:

While the specific actions to be identified may be plant-specific, in general, the following types of actions are expected to be identified. Note that actions that are heroic (e.g., must enter an extreme high radiation environment) or without any procedure guidance or not trained on, should not be included or credited in the analysis (exceptions may be able to be justified, but this should not be normal practice).

- Include necessary and desired/expected actions (e.g., initiate RHR, control vessel level, isolate a faulted steam generator, attempt to reclose a stuck-open relief valve).

- Include backup actions to failed automatic responses (e.g., manually start a diesel generator that should have auto started) but be sure the action can be credited to recover the auto failure mode.

- Include anticipated procedure-guided or skill-of-the-craft recovery actions (e.g., restore offsite power, align firewater backup) although these may best be defined later as the PRA quantification begins and important possible recovery actions become more apparent.

Consistent with present day state-of-the art, acts whose failure involve an error of omission (EOO) should be included when identifying post-initiator acts of concern. These involve failure to take the appropriate actions as called out in the procedures and/or trained on or expected as common practice. For example, failure to initiate feed and bleed or failure to start standby liquid control, are EOOs. Possible acts whose failure would involve an error of commission (EOC) are generally beyond current

PRA practice. These involve performing expected acts incorrectly or performing extraneous and detrimental acts such as shutting down safety injection when it is not appropriate. These are not necessarily expected to be identified but see Section 7 of this document for more on this subject.

Finally, it should be recognized that iterations as well as refinement and review of the PRA model construction may (and often do) provide additional opportunities to identify any potentially important missed actions as the PRA model evolves.

5.1.4 POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:

While not all the post-initiator actions will be important in the final assessment of risk, unlike the pre-initiator actions, it is difficult to predetermine (at this stage) a set of actions that do not have to be included as part of the identification process. Ways the operators interact with the plant and affect the outcome of any accident sequence need to be assessed in order to determine their relative significance. Hence the good practices herein are aimed at ensuring potentially risk-significant post-initiator actions (based on the procedures as well as the ways the procedures are interpreted and carried out) are identified at this stage of the analysis. Otherwise, the model could be incomplete and/or inaccurate, potentially resulting in misinformation as to the risk dominant plant features (including the important human actions).

5.2 Modeling specific human failure events (HFEs) corresponding to the human failures

5.2.1 OBJECTIVE: To define how each specific post-initiator HFE is to be modeled in the PRA to accurately represent the failure of each action identified. This involves the modeling of the HFEs as human-induced unavailabilities of functions, systems, or components consistent with the level of detail in the PRA accident sequences and system models, possible grouping of responses into one HFE, and ensuring the modeling reflects certain plant-specific and accident sequence-specific considerations. The following provides good practices for modeling post-initiator human failure events while implementing the related Standard requirements.

5.2.2 CORRESPONDING ASME STANDARD REQUIREMENTS:

The Standard calls for the HFEs to be defined so that they represent the impact of not properly performing the required responses, consistent with the structure and level of detail of the accident sequences. There are multiple supporting requirements in the Standard that address the modeling level of detail for each HFE and how to complete the definition of each HFE.

5.2.3 GOOD PRACTICES:

5.2.3.1 Good Practice #1:

Define each specific post-initiator HFE to be modeled in the PRA as a basic event that describes the human failure of not properly performing the required response and is located in the model such that it is linked to the unavailability of the affected component, train, system, or overall function (i.e., level of modeling) depending on the effect(s) of the HFE (e.g., failure to manually depressurize using the safety relief valves, failure to manually scram, failure to align the backup train of service water). The following considerations should be used to define the post-initiator failure level properly in the PRA:

- the nature of the action is performed on a train, system, etc. level so it makes more sense to define the HFE at that level,

- the consequences of the failure and what would be affected by the failure (just a component is affected, a whole train, a system, multiple systems, an entire function),
- multiple individual acts/responses such as at a system or component level (e.g., starting high pressure injection and then subsequently opening a power-operated pressurizer relief valve) can be combined as a single post-initiator HFE affecting a higher level of equipment resolution such as at a system or a function level (e.g., initiating feed and bleed) as long as (a) the acts and effects are related, (b) how the single HFE will be quantified (i.e., the performance-shaping factors that would affect quantification as discussed later) is not significantly different or will be conservatively bounding than if the individual acts were to be modeled and quantified separately, and (c) there are no potential commonalities/dependencies with other post-initiator acts elsewhere in the model so that potential common failures among similar individual acts might be missed (see the discussion presented below),

- the level of detail already modeled in the PRA (train, system, etc.) for failures of the associated equipment (less important factor).

As an example of how human responses may be grouped and modeled as one or more HFEs, consider the case in a boiling water reactor (BWR) of a desired response to control reactivity in an anticipated transient without scram scenario. Failure to control reactivity could be defined as one HFE, or as several HFEs based on the subtasks involving inhibiting the automatic depressurization system, lowering reactor water level, and initiating the standby liquid control system.

For situations such as the above example, if failure to perform the subtasks (a) have different effects, (b) may individually be impacted by very different performance-shaping factors (e.g., in-control room actions vs. local actions in a high steam environment area, a subtask performed early in the scenario vs. another subtask performed much later in the scenario), or (c) involves an action that has a dependency with some other action to be modeled in the PRA (e.g., failure to trip two reactor coolant pumps followed by subsequent failure to trip the remaining reactor coolant pumps when conditions warrant), the failures are best modeled as separate HFEs. An alternative is to model them all as one HFE and model the bounding consequence (such as the failure to control reactivity example cited above) as long as the most limiting performance-shaping factors are used (e.g., the shortest time that any of the subtasks must be performed, the most complex of the subtasks, etc.) and any subtask dependencies with other HFEs are identified, treated in the model, and properly quantified.

The failure effects as depicted in the PRA model should be a direct result of considering the equipment affected and the effects of the human-induced failure (refer to the Good Practices under Section 5.1.3) and stem from failure to properly perform the correct responses. The failures should sufficiently describe the HFE and its effect to ensure proper interpretation of the HFE in the model (e.g., fail to initiate feed and bleed within 5 minutes of the reactor pressure achieving 2400 psig).
As an aid to ensure appropriate modeling, it is recommended practice (but not necessary) that the post-initiator failure be placed in close proximity, in the PRA model, to the component, train, system, or

function affected by the human failure. In this way, a quick examination of the model can reveal the modeled effect of the human failure.

5.2.3.2 Good Practice #2:

Each of the modeled post-initiator HFEs should be defined such that they are plant- and accident sequence-specific. Where helpful to fully understand the nature of the act(s) (e.g., who performs it, what is done, how long does it take, are there special tools needed, are there environmental issues or special physical needs, etc.), use of talk-throughs, walkdowns, field observations, and simulations are particularly encouraged.

In order for the act to occur, the operator must diagnose the need to take the act and then execute the act. While many performance-shaping factors are used to quantify the probability for failing to perform the act correctly (as discussed later under quantification), all of which should be evaluated based on plant and accident sequence-specifics, the following requirements are particularly germane to a basic understanding of the HFE and should be met to complete the definition of each HFE:

- to the extent possible, the time by which the act needs to be performed (e.g., fail to initiate feed and bleed by 2 minutes after primary pressure reaches 2400 psig), and the time necessary to diagnose the need for and to perform the act (1 minute) should be based on plant and accident sequence-specific timing and nature of the complexity and/or subtasks involved in implementing the act (i.e., not another plant analysis or a general analysis for the "average" plant since the number and nature of the specific manipulations could be different, the plant thermal hydraulic response could be different, the location for local actions may require different travel times, some sequences require a fast response while others may require a much quicker response for the same act, etc.),

- similar to the above, the availability and timing of plant and accident sequence-specific cues (i.e., indications, alarms, visual observations, etc. and when they will be manifested) should be used as these can be different from plant-to-plant and different in a variety of accident sequences (e.g., such as a DC bus failure causing loss of some indications or alarms), and will affect the likelihood and timing of diagnosing the need for the action,

- plant-specific procedure and training guidance should be used based on the reviews under the Good Practices in Section 5.1.3,

- where the act is performed (e.g., in the control room, locally in the auxiliary building) should be noted, and

- the use of walkdowns, talk-throughs, and field or simulator observations are encouraged when defining the HFE as mentioned under Good Practice #1 under Section 5.1.3. See more about the benefits of these techniques in Appendix A.

5.2.4 POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:

The precise definition of the post-initiator basic events and their placement in the model (from both a logic and failure mode standpoints) ultimately define how the model addresses the effects of the human failures. This needs to be done accurately if the model is going to logically represent the real effects of each human failure and if the corresponding HFE is going to be correctly quantified (as discussed later). This accuracy is best obtained if plant-specific and accident sequence-specific information is used. Nevertheless, the following observation is noted.

- Not using plant/accident sequence-specific thermal hydraulic information for timing may or may not be critical based on the relevancy and thus appropriateness of the non-specific (i.e., "general") timing information that is used. It is better to use plant and accident-specific information, though it is recognized that in some areas (e.g., containment response for LERF), from a practical standpoint, modified "general" information may be all that is readily available. Further, as long as the timing considerations used are reasonable and accurate to within the resolution of the HRA quantification tool to be used, differences between plant and accident-specific vs. more "general" timing considerations may not be a significant issue. Analysts should ensure that if non-specific timing information is used, it is reasonable to expect it to be appropriate for the plant and accident sequence being analyzed.

5.3 Quantifying the corresponding human error probabilities (HEPs) for the specific HFEs

5.3.1 OBJECTIVE: To address how the human error probabilities (HEPs) for the modeled HFEs from the previous analysis activity are to be quantified. This section provides good practices guidance on an attribute or criteria level and does not endorse a specific tool or technique. Ultimately, it is these probabilities along with the other equipment failure and pre-initiator human error probabilities as well as initiating event frequencies that are all combined to determine such risk metrics as CDF, LERF, ΔCDF, ΔLERF, etc. as addressed in Regulatory Guide 1.174[11]. The following provides good practices for quantifying post-initiator HEPs while implementing the related Standard requirements.

5.3.2 CORRESPONDING ASME STANDARD REQUIREMENTS:

The Standard requires that a well-defined and self-consistent process be used to quantify the post-initiator HEPs. There are multiple supporting requirements in the Standard that address many factors associated with quantifying the HEPs. These include when conservative vs. detailed estimates are appropriate, consideration of cognitive and execution failures, performance-shaping factors considered in the evaluations, consideration of dependencies among HFEs, uncertainty, and reasonableness of the HRA results.

5.3.3 GOOD PRACTICES:

5.3.3.1 <u>Good Practice #1:</u>

Whether using conservative or detailed estimation of the post-initiator HEPs, the evaluation should include both cognitive (i.e., "thinking) as well as execution failures. For example, incorrectly interpreting a cue or not seeing a cue and thus not performing the act can be one mode of failure. Or, the operator can intend to take the act based on the proper and recognized cues but still otherwise fail to take the act or perform it correctly. Both need to be part of the HEP evaluations.

5.3.3.2 Good Practice #2:

The use of conservative human error probability (HEP) estimates is virtually necessary during the early stages of PRA development and quantification. This is acceptable (and almost necessary since not all the potential dependencies among human events can be pre-known) provided (a) it is clear that the individual values used are over-estimations of the probabilities if detailed assessments were to be performed AND (b) dependencies among multiple human failure events appearing in an accident sequence are conservatively accounted for. These conservative values should be set so as to be able to make the PRA quantification process more efficient (by not having to perform detailed analysis on every human failure event), but not so low that later detailed analysis would actually result in higher HEPs. The conservative estimates should consider both individual HEPs and the potential for multiple and possibly dependent human failure events for a given accident sequence (scenario). To meet these conditions, it is recommended that (unless a more detailed assessment is performed of the individual or combination events to justify lower values):

- no individual post-initiator HEP conservative value should be lower than the worse case anticipated detailed value and generally not lower than 0.1 (typical of high post-initiator values in PRAs), and

- multiple HEPs in the same sequence should not have a joint probability value lower than the worse case anticipated detailed joint probability value and generally not lower than 5E-2 (accounts for a 0.5 high dependency factor) at this stage.

5.3.3.3 Good Practice #3:

As needed for the issue being addressed to produce a more realistic assessment of risk, detailed assessments (not just conservative estimates) of at least the dominant human failure event contributors should be performed. The PRA analyst can define the dominant contributors by use of typical PRA criteria (not addressed here) such as importance measure thresholds as well as other qualitative and quantitative considerations. While the use of conservative values may, at first, seem to be a "safe" analysis process, it can have negative impacts. Conservative values can focus the risk on inappropriate human actions or related accident sequences and equipment failures because of the intentionally high HEPs. Such incorrect conclusions need to be avoided by ensuring a sufficient set of more realistic, detailed HEPs are included in the model.

5.3.3.4 Good Practice #4 (application-specific):

For a specific PRA application and depending on the issue being addressed (e.g., examination of a specific procedure change), revisit the use of conservative vs. detail-assessed HEPs to ensure issue-relevant human actions have not been prematurely deleted from the PRA or there is an inappropriate use of conservative vs. detailed values to properly assess the issue and the corresponding risk.

5.3.3.5 Good Practice #5:

As "good practice," the following table of performance-shaping factors (Table 5-1) for both in-control room and ex-control room (local) actions should be treated in the evaluation of each HEP per the table guidance. The guidance should fit most cases, but it should be recognized that for specific actions, some of the factors may not apply while others may be so important, the others do not matter (e.g., time available is so short, the act almost assuredly cannot be done regardless of the other factors). Further, if a specific situation warrants treatment of unique factors that are not, and cannot be

Table 5-1 Post-Initiator PSFs To Be Considered

In-Control Room Actions		Ex-Control Room Actions	
Always Consider the Following PSFs		**Always Consider the Following PSFs**	
Applicability and suitability of training and experience		Applicability and suitability of training and experience	
Suitability of relevant procedures and administrative controls		Suitability of relevant procedures and administrative controls	
Availability and clarity of instrumentation (cues to take actions as well as confirm expected plant response		Availability and clarity of instrumentation (cues to take actions as well as confirm expected plant response	
Time available and time required to complete the act, including the impact of concurrent and competing activities		Time available and time required to complete the act, including the impact of concurrent and competing activities	
Complexity of required response along with workload, time pressure, the need for special sequencing, and familiarity		Complexity of required response along with workload, time pressure, the need for special sequencing, and familiarity	
Team/crew dynamics and crew characteristics (degree of independence among individuals, operator attitudes - biases - rules, use of status checks, approach for implementing procedures, e.g., aggressive vs. slow and methodical...)			
Consideration of 'realistic' accident sequence diversions and deviations (e.g., extraneous alarms, failed instruments, outside discussions, sequence evolution not exactly like that trained on..) (Better Practice)			
Additional PSFs to Consider	**Conditions When Particularly Relevant**	**Additional PSFs to Consider**	**Conditions When Particularly Relevant**
Available staffing and resources	If typical CR staff is expected to be decreased or impacted so others must perform more than their typical tasks (not usually an issue)	Available staffing and resources	Particularly when many or complex actions need to occur concurrently or in a short time, and staffing needs may be stretched

In-Control Room Actions		Ex-Control Room Actions	
Human-machine interface	If could be problematic, or not easily accessed or used (not usually an issue but consider, for instance, the need to use backboards, deal with common workarounds...)	Human-machine interface	If could be problematic (e.g., poor labeling) or not easily accessed or used
Additional PSFs to Consider	**Conditions When Particularly Relevant**	**Additional PSFs to Consider**	**Conditions When Particularly Relevant**
Environment in which the act needs to be performed	Potentially adverse or threatening situations such as fire, flood, seismic, loss of ventilation...(not usually an issue)	Environment in which the act needs to be performed	Potentially adverse situations such as high radiation, high temperature, high humidity, smoke, toxic gas, noise, poor lighting, weather, flooding, seismic...
Accessability and operability of equipment to be manipulated	If could be problematic, or not easily accessed or used such as the need to use backboards, or when indications/controls could be affected by the initiating event or other failures (e.g., loss of DC)	Accessability and operability of equipment to be manipulated	If could be problematic, or not easily accessed or used such as when the equipment could be affected by the initiating event or the environment (e.g., fire, flood, weather)
The need for special tools (keys, ladders, hoses, clothing such as to enter a radiation area...)	Not usually an issue but consider, for instance, accessability of keys for keylock switches	The need for special tools (keys, ladders, hoses, clothing such as to enter a radiation area...)	For situations where other than simple switch or similar type operations are necessary, or when needed to be able to access the equipment

In-Control Room Actions		Ex-Control Room Actions	
Communications (strategy and coordination) as well as whether one can be easily heard	Not usually an issue - simply ensure that communication strategy allows crisp direction and proper feedback; otherwise only in special situations such as needing to communicate with SCBAs on	Communications (strategy and coordination) as well as whether one can be easily heard	For situations where communication among crew members (locally and/or with CR) are likely to be needed and there could be a threat such as too much noise, failure of the communication equipment, availability and location issues associated with the communication equipment...
Additional PSFs to Consider	**Conditions When Particularly Relevant**	**Additional PSFs to Consider**	**Conditions When Particularly Relevant**
Time of day	Special sequences or events such as involving numerous failures where task workloads may be extremely high and preferred additional in-CR staffing needs may be difficult to obtain such as during graveyard shift (typically not an issue)	Time of day	Particularly when many or complex actions need to occur concurrently or in a short time, and staffing needs may be stretched such as during graveyard shift
		Special fitness needs	For special situations expected to involve the use of heavy or awkward tools/equipment, carrying hoses, climbing...
		Team/crew dynamics and crew characteristics (degree of independence among individuals, operator attitudes - biases - rules, use of status checks, approach for implementing procedures, e.g., aggressive vs. slow and methodical...)	To the extent that the timing and the appropriateness of the directions from the CR, and the subsequent carrying out of the ex-CR action(s) could be affected

In-Control Room Actions		Ex-Control Room Actions	
		Consideration of 'realistic' accident sequence diversions and deviations (e.g., extraneous alarms, outside discussions, sequence not exactly like that trained on...)	To the extent that these could affect the timing, specific directions, or successful performance of the ex-CR action(s)

addressed by the following list of factors, identification of other performance-shaping factors should complement the list below. Consideration of the impact of the factors on the HEPs should be as plant- and accident sequence-specific as necessary to address the issue and confirmed, where useful, by such techniques as talkthroughs, walkdowns, field observations, simulations, and examination of past events in order to be realistic. Appendix A provides more specific guidance and discussion of the PSFs presented below, as well as why some are considered generally more important than others.

It should be apparent that the factors seemingly most relevant to the act (either as positive or negative influences) and having the most impact on the HEP, have been considered quantitatively. Further, the more the impacts of the factors have been determined based on talkthroughs, walkdowns, field observations, and simulations vs. simple assumptions or judgements, the better the quality of the HEP evaluations.

5.3.3.6 Good Practice #6:

Dependencies among the post-initiator HFEs and hence the corresponding HEPs in an accident sequence should be quantitatively accounted for in the PRA model by virtue of the joint probability used for the HEPs. This is to account for the evaluation of each sequence holistically, considering the performance of the operators throughout the sequence response and recognizing that early operator successes or failures can influence later operator judgments and subsequent actions. This is particularly important so that too optimistic combined probabilities are not inadvertently assigned potentially resulting in the inappropriate decrease in the risk significance of human actions and related accident sequences and equipment failures. In the extreme, this could result in the inappropriate screening out of accident sequences from the model because the combined probability of occurrence of the events making up an accident sequence drops below a threshold value used in the PRA to drop sequences from the final risk results.

In analyzing for possible dependencies among the HFEs in an accident sequence, look for links among the acts including:

- the same crew member(s) is responsible for the acts,

- the actions take place relatively close in time in the sense that a crew "mindset" or interpretation of the situation might carryover from one event to the next,

- the procedures and cues used along with the plant conditions related to performing the acts are identical (or nearly so) or related, and the applicable steps in the procedures have few or no other steps in between the applicable steps,

- there are similar performance shaping factors for performing the acts,

- how the acts are performed is similar and they are performed in or near the same location, and

- there is reason to believe that the decision processes associated with the events might be related and the interpretation of the need for one action might bear on the crews decision regarding another action.

The more the above commonalities and similarities exist, the greater the potential for dependence among the HFEs (i.e., if the first act is not performed correctly, there is a higher likelihood the second, third... act(s) will also not be performed correctly; or vice versa if the act(s) are successful). For example, if nearly all or all of the above characteristics exist, very high or complete dependence should generally be assumed. If only one or two of the above characteristics exist, then analysts will need to evaluate the likely strength of their effect and the degree of dependence that should be assumed and addressed in quantification.

The resulting joint probability of the HEPs in an accident sequence should be such that it is in line with the above characteristics and the following guidance, unless justified otherwise:

- The total combined probability of all the HFEs in the same accident sequence/cut set should not be less than a justified value. It is suggested that the value not be below the ~0.0001 to 0.00001 range since it is typically hard to defend that other not specifically treated dependent failure modes (e.g., even heart attack) cannot occur. Depending on the independent HFE values, the combined probability may need to be higher.

- To the extent the joint HEPs are looked at separately, but a previous human action in the sequence has failed, then:

    - A factor of 3-10 higher than what would have been the independent HEP value for the subsequent act(s) exists for low to moderate dependence

    - 0.1 up to 0.5 is the resulting probability value used for the subsequent HEP(s) for high dependence

    - ≥0.5 exists for the subsequent HEP(s) for very high or 1.0 for complete dependence.

5.3.3.7 Good Practice #7:

Mean values for each HEP (excluding conservative HEPs) and an assessment of the uncertainty in the mean values should be performed at least for the dominant HEPs to the extent that these uncertainties need to be understood and addressed in order to make appropriate risk-related decisions. Assessments of uncertainty are typically performed by:

- assigning uncertainty distributions for the HEPs and propagating them thru the quantitative analysis of the entire PRA such as by a Monte Carlo technique, and/or

- performing sensitivity analyses that demonstrate the effects on the risk results for extreme estimates in the HEPs based on at least the expected uncertainty range about the mean value.

Note, in some cases, it may be sufficient to address the uncertainties by just qualitative arguments without the need to specifically quantify them (e.g., justifying why the HEP cannot be very uncertain or why a change in the HEP has little relevancy to the risk-related decision to be made).

In assessing the uncertainties and particularly when assigning specific uncertainty distributions, the uncertainties should include (a) those epistemic uncertainties existing because of lack of knowledge of the true expected performance of the human for a given context and associated set of performance-shaping factors (i.e., those factors for which we do not have sufficient knowledge or understanding as to the "correct" HEP, such as how time of day affects the bio-rhythm and hence performance of operators), and (b) consideration of the combined effect of the relevant aleatory (i.e., random) factors to the extent they are not specifically modeled in the PRA and to the extent that they could significantly alter the context and performance-shaping factor evaluations for the HFE, and thereby the overall HEP estimate.

Concerning the latter, while it is best to specifically model the aleatory factors in the PRA (i.e., those factors that are random and could significantly affect operator performance, for example, the time of day the initiator occurs, whether or not other nuisance alarms or equipment failures may co-exist with the more important failures in the sequence, whether a critical equipment failure occurs early in the sequence or late in the sequence, etc.), this is often impractical and is typically not done as it would make the PRA model excessively large and unwieldy. Thus in assigning the mean HEP and uncertainty distribution, analysts should reflect an additional contribution from random factors associated with the plant condition or overall action context. This can be done by considering the relevant aleatory (i.e., random) factors, their likelihoods of occurrence, and their effects on the HEP estimate.

For example, suppose for an accident sequence(s) it is judged that the human performance will be significantly affected by the number of "nuisance and extraneous failures," as opposed to when no or few nuisance/extraneous failures exist (and yet these two plant "states" are not explicitly defined by the PRA model). Further, based on the analyst considering how the HEP is affected, a value of P_o would be estimated for when no or few nuisance/extraneous failures exist and a value of P_1 would be estimated for when many do exist, and the difference between P_o and P_1 is significant (e.g., factor of 10). It is also judged that many nuisance/extraneous failures will occur about 50% of the time based on past experience. The resulting combined mean HEP value is $0.5P_o + 0.5P_1$ considering this random factor. The overall uncertainty about the combined mean HEP value should reflect the weighted epistemic uncertainties in P_o and P_1 (such as by a convolution approach, via an approximation, or other techniques). While it is not expected that such a detailed evaluation be done for every random situation or for every HEP, the mean and uncertainty estimates for the most dominant HEPs should account for any such perceived important aleatory factors that have not otherwise been accounted for (i.e., the factors, considering their likelihoods and effects on the HEP, are anticipated to have a significant impact on the resulting overall HEP).

Whatever uncertainty distributions are used, the shape of the distributions (log-normal, normal, beta...) are typically unimportant to the overall risk results (i.e., the PRA results are usually not sensitive to specific distributions). Further, typical uncertainties include values for the HEP that represent a factor of 10 to 100 or even more between the lower bound value and the upper bound value that encompass the mean value.

5.3.3.8 Good Practice #8:

The post-initiator HEPs (excluding the conservative HEPs) should be reasonable from two standpoints:

- first and foremost, relative to each other (i.e., the probabilistic ranking of the failures when compared one to another), and

- in absolute terms (i.e., each HEP value) to the extent that the sensitivity of the risk-related decision is not important as to the absolute values for the HEPs.

This reasonableness should be checked based on consideration of actual plant experience and history, against other evaluations (such as for similar acts at other plants), and the qualitative understanding of the actions and the relevant contexts and performance-shaping factors under which the acts are performed.

It is suggested that a rank-ordered list of the post-initiator HFEs by probability be used as an aid for checking reasonableness. As part of such a list, it is particularly worthwhile to compare "like" HFEs for different sequences such as failure to manually depressurize in a BWR when all high pressure injection is lost during a LOCA as compared to the same action but during a simple transient. For example, simple, procedure-guided actions with easily recognized cues and plenty of time to perform the actions, should have lower HEPs than complex, memorized, short time available type actions, all other factors being the same. Typical expectations of most post-initiator HEPs are in the 01 to 0.0001 range and depend particularly on the relevant contextual factors and proper consideration of dependencies as discussed under many of the Good Practices covered above. Helpful checks include:

- For a HFE, do any one or two dominant performance-shaping factors exist or is the cumulative effect of the relevant performance-shaping factors such that they are either so negative or so positive that a 'sanity check' would suggest a high HEP (e.g., 0.1) or a low HEP (e.g., 1E-4) respectively? Accordingly, this very high or low probability HFE should be one of the higher or lower probability HFEs relative to the other HFEs in the model. For example, while the manual scram action may need to be done in a short time, it is a proceduralized action, is often an early step in procedures, is performed often in training, and thus has become such an "automatic" action (the predominant positive factor) that a low HEP is justified.

- Are there seemingly balanced combinations of both positive and negative factors, or are there weak to neutral factor effects? If so, this is likely to lead to in-between values for the HEPs (e.g., ~0.01) placing these HFEs (relative to others) 'in the middle'.

- Do the individual HEPs and the relative ranking of the HFEs seem consistent with actual or simulated experience? For example, if it is known that operators 'have trouble with' a specific act(s) in simulations or practiced events, and yet the assigned HEP is very low (e.g., 1E-3 or lower), this may be a reason to question and revisit the assigned HEP.

- Do other similar plant and action analyses support the HEP evaluation? Recognize, however, that there may be valid reasons why differences may exist and thus this check is not likely to be as helpful as the others above.

5.3.4 POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:

Besides the obvious concerns about inaccuracies in the HEP quantification and thus whether the HEPs "make sense", as well as the resulting potential misinformation about the dominant risk contributors if quantification is not done well, the following observations are noted.

- Use of conservative values is a useful and most often, necessary part of HRA so as to avoid the expenditure of resources on unimportant human events and accident sequences. The above guidance is aimed at allowing some conservative values without inadvertently and inappropriately allowing the analytical phenomenon of, for instance, multiplying four human events in the same sequence each at a conservative estimate of 1E-1 to yield a 1E-4 combined probability, without checking for dependencies among the human events. In such a case some human failure events and combinations of events, or even whole accident sequences, may inappropriately screen out of the PRA model entirely because the accident sequence frequency drops below a model threshold. Hence some of the dominant individual or combination contributors may be missed. This is why the conservative estimates both individually and for combined events should not be too low. Further, if conservative values are left permanently assigned to some human failure events that should be assessed with more detail to obtain a more realistic assessment of risk (supposedly lowering the probability), the risk significance of these human failure events and related equipment failures are likely to be over-emphasized at the expense of improperly lessening the relative importance of other events and failures.

- It is important to be sure that dependencies among the various modeled HFEs including those with conservative values, have been investigated. Treating HFEs, whether with conservative values or based on more detailed analysis, as independent acts without checking for dependencies (thereby being able to multiply the individual HEPs) can inappropriately lessen the risk significance of those HFEs and related equipment failures in accident sequences. This can cause the inappropriate dropping out of accident sequences because the sequences quantitatively drop below a model threshold value as discussed above under screening. Proper consideration of the dependencies among the human actions in the model is necessary to reach the best possible evaluation of both the relative and absolute importance of the human events and related accident sequence equipment failures.

- The use of mean values and addressing uncertainties are a part of the Regulatory Guide 1.174[11] guidance and to the extent addressed therein, the HRA quantification needs to be consistent with that guidance when making risk-informed decisions.

- There can be a tendency for analysts to want to use an existing PRA model to address issues such as changes to the plant, without spending the appropriate time to revisit some of the underlying assumptions and modeling choices made to create the original PRA. A review should be done to see if these assumptions and choices still apply for the issue being addressed. In this case, some post-initiator human failure events may be quantified in the original model using conservative estimates and detailed failure probabilities that may not be appropriate for the new issue being addressed. As an example, where higher conservative values may have been acceptable for purposes of the original PRA, these may over-estimate the contribution of these human failure events for the issue being addressed. Further, the relative risk contribution of equipment and associated accident sequences with which the human failure events appear, may be artificially too high (and therefore other events too low) because of the conservative values. Hence it is good practice to revisit the use of conservative estimates and detailed human failure event probabilities in order to appropriately address the issue.

5.4 Adding recovery actions to the PRA

5.4.1 OBJECTIVE: To address what recovery actions can be credited in the post-initiator HRA and the requirements that should be met before crediting recovery actions. Adding recovery actions is common practice in PRA and accounts for other reasonable actions the operators might take to avoid severe core damage and/or a large early release that are not already specifically modeled. For example, in the PRA modeling of an accident sequence involving a loss of offsite power, subsequent station blackout, and loss of all injection, it would be logical and common to credit the operators attempting to recover offsite or onsite power (and thus ac-powered core cooling systems) as well as perhaps locally aligning an independent firewater system (not affected by the station blackout) for injection. The failure to successfully perform such actions would subsequently be added to the accident sequence model thereby crediting the actions and further lowering the overall accident sequence frequency because it takes additional failure of these actions before the core is actually damaged. The following provides good practices for crediting post-initiator recovery actions while implementing the related Standard requirements.

5.4.2 CORRESPONDING ASME STANDARD REQUIREMENTS:

> The Standard requires that recovery actions be modeled only if it has been demonstrated that the action is plausible and feasible for those sequences to which they are applied. There are multiple supporting requirements in the Standard that address what recovery actions can be credited as well as the need to consider dependencies among the HFEs and any recovery actions that are credited.

5.4.3 GOOD PRACTICES:

5.4.3.1 <u>Good Practice #1:</u>

Based on the failed functions, systems, or components, identify recovery actions to be credited that are not already included in the PRA (e.g., restoring offsite power loss, aligning another backup system not already accounted for...) and that are appropriate to be tried by the crew to restore the failure. The following should be considered in defining appropriate recovery actions:

- the failure to be recovered,

- whether the cues will be clear and provided in time to indicate the need for a recovery action, and the failure that needs to be recovered,

- the most logical recovery actions for the failure and based on the cues that will be provided,

- the recovery is not a repair action (e.g., the replacement of a motor on a valve so that it can be operated),

- whether sufficient time is available following the timing of the cues (for the sequence/cut set) for the recovery action to be diagnosed and implemented to avoid the undesired outcome,

- whether sufficient crew resources exist to perform the recovery(ies),

- whether there is procedure guidance to perform the recovery(ies),

- whether the crew has trained on the recovery action(s) including the quality and frequency of the training,

- whether the equipment needed to perform the recovery(ies) is accessible and in a non-threatening environment (e.g., extreme radiation), and

- whether the equipment needed to perform the recovery(ies) is available in the context of other failures and the initiator for the sequence/cut set.

In addressing the above issues and assessing which recovery action, or a few, to credit in the PRA, just as with any other HFE, all the good practices provided earlier in Sections 5.1, 5.2, and 5.3 apply to these recovery actions as well (i.e., the failure to recover is just another HFE like all the other post-initiator HFEs). In general, no recovery should be credited where any of the above considerations are not met (e.g., there is not sufficient time, there are no cues that there is a problem, there are not sufficient resources, there is no procedure or training, etc.). Exceptions may be able to be justified in unique situations, such as a procedure is not needed because the recovery is a skill-of-the-craft, non-complex, and easily performed; or the specific failure mode of the equipment is known for the sequence (this is usually not the case at the typical level of detail in a PRA) and so "repair" of the failure can be credited because it can be easily and quickly diagnosed and implemented. Any exceptions should be documented as to the appropriateness of the recovery action.

When considering multiple recoveries (i.e., how many recoveries to be credited in one accident sequence/cut set), the above considerations apply to all the recoveries. The analyst should also consider that one recovery may be tried (perhaps even multiple times) and then the second recovery may be tried but with even less time and resources available because of the attempts on the first recovery. Hence the failure probability of the second recovery should be based on more pessimistic characteristics (e.g., less time available, less resources, etc.) than if such a possibility is not considered.

5.4.3.2 Good Practice #2:

As stated above, all the good practices provided earlier in Sections 5.1, 5.2, and 5.3 apply. From these good practices, particular attention should be paid to accounting for dependencies among the HFEs including the credited recovery actions. More specifically, dependencies should be assessed:

- among multiple recoveries in the accident sequence/cut set being evaluated, and
- between each recovery and the other HFEs in the sequence/cut set being evaluated..

As part of this effort, the analyst should give proper consideration to the difficulties people often have in overcoming an initial mind-set despite new evidence (e.g., look how long the PORV remained open in the Three Mile Island accident despite new cues of the problem, different personnel, etc.). For this and similar reasons, the assessing of no dependence needs to be adequately justified to ensure the quantified credit for the recovery action(s) is not unduly optimistic.

5.4.3.3 Good Practice #3:

Quantify the probability of failing to perform the recovery(ies) by:

- using representative data that exists and deemed appropriate for the recovery event (i.e., a data-based approach such as using data that exists for typical times to recover offsite power)

- using the HRA method/tool(s) used for the other HFEs (i.e., using an analytical/modeling approach).

In performing the quantification, one should ensure that all the good practices under Section 5.3 are followed (for each individual recovery as well as for multiple/joint recovery credit). In addition, if using data, ensure the data is applicable for the plant/sequence context or that the data is modified accordingly. For example, a plant may use available experience data for the probability of failing to align a firewater system for injection but the experience data is based on designs for which all the actions can be taken from the main control room whereas for this plant, the actions have to be performed locally.

5.4.4 POSSIBLE IMPACTS OF NOT PERFORMING GOOD PRACTICES AND ADDITIONAL REMARKS:

The primary concern for not performing the above good practices is that recovery credit could be applied too optimistically; that is, the failure to recover is assigned too low a probability. Hence an under-estimate of the failure to recover is applied to the PRA accident sequence/cut set, making the affected sequence/cut set artificially too low in risk significance. This can subsequently affect the ranking of the important sequences, equipment failures, and human actions potentially leading to false conclusions of the dominant risk contributors.

6. HRA DOCUMENTATION

The ASME Standard[5] provides a set of requirements for documenting a human reliability analysis (HRA) in a manner that facilitates PRA applications, upgrades, and peer review. Specific requirements are provided. The following provides good practice for documenting a HRA building on those requirements.

<u>Good Practice:</u>

The level of detail that needs to be addressed in the documentation is dependent on the PRA application and the issue being addressed as well as the objectives, scope, and level of detail of the analysis. Whatever documentation is provided, the test for adequate documentation should be: "Can a knowledgeable reviewer understand the analysis to the point that it can be at least approximately reproduced and the resulting conclusion reached if the same methods, tools, data, key assumptions, and key judgments and justifications are used?" Hence, the documentation should include the following, but only to the extent it is applicable for the application:

- the overall approach and disciplines involved in performing the HRA including to what extent talk-throughs, walkdowns, field observations, and simulations were used,

- summary descriptions of the HRA methodologies, processes, and tools used to:

    - identify the pre-and post-initiator human actions,
    - screen pre-initiators from modeling,
    - model the specific HFEs including decisions about level of detail and the grouping of individual failures into higher order HFEs,
    - quantify the HEPs with particular attention to the extent to which plant and accident sequence-specific information was used, as well as how dependencies were identified and treated,

- assumptions and judgments made in the HRA, their bases, and their impact on the results and conclusions (generic or on a HFE-specific basis, as appropriate),

- for at least each of the HFEs important to the risk decision to be made, the PSFs considered, the bases for their inclusion, and how they were used to quantify the HEPs, along with how dependencies among the HFEs and joint probabilities were quantified,

- the sources of data and related bases or justifications for:

    - the screening and conservative values,
    - the best estimate values and their uncertainties with related bases,

- the results of the HRA including a list of the important HFEs and their HEPs, and

- conclusions of the HRA.

7. ERRORS OF COMMISSION (EOCs)

Explicit modeling of errors of commission (i.e., committing an incorrect act) has generally been beyond current PRA practice and is not explicitly addressed in the ASME Standard HRA requirements. This is largely because practitioners believe that there is potentially a large number of acts that an operator might perform that are adverse to safe shutdown (i.e., fail or make unavailable equipment/functions relevant to mitigating the scenario, or otherwise exacerbate the scenario such as opening a PORV and causing an unwanted loss of coolant accident) even for what may appear to be justifiable reasons. Errors of omission (i.e., failure to perform the correct act) are typically modeled in PRAs because the set of correct acts is better known for each sequence, thus limiting the number of human failures that need to be modeled. At best, PRAs have handled EOCs implicitly (e.g., as part of a base HEP) without a systematic or adequate search for this type of error.

However, more recent methods (e.g., ATHEANA) are making advances in the ability to identify EOCs without the need of performing an exhaustive search. One of the lessons learned from the development and application of ATHEANA is that the effort needed to identify EOCs can be substantially reduced by focusing the search on identifying systematic vulnerabilities in plant operations associated with plant critical functions.

Given these advances and the potential for regulatory requirements to make the need to address EOCs more important, it is recommended that future HRA/PRAs attempt to identify and model potentially important EOCs. At a minimum, the use of risk in any issue assessment should at least ensure that conditions that promote likely EOCs do not exist, e.g., that such conditions have not been introduced by a plant change or modification. To the extent any EOCs are modeled, all the guidance in this document has been written with both types of errors in mind; that is, all the same good practices apply whether the error is one of omission or commission.

When considering the potential for situations that may make EOCs somewhat likely, the premise of any evaluation should be that:

- operators are performing in a rationale manner (e.g., no sabotage), and
- the procedural and training guidance is being used by the crew based on the plant status inputs they are receiving.

Using this premise, EOCs are considered to be largely the result of problems in the plant information/operating crew interface (wrong, inadequate information is present, or the information can be easily misinterpreted) or in the procedure-training/operating crew interface (procedures/training do not cover, very well, the actual plant situation because they provide ambiguous guidance, no guidance, or even unsafe guidance for the actual situation that may have evolved in a somewhat unexpected way).

With a present focus on reviewing potential applications of current PRAs, the following is offered as guidance in this area to aid in ensuring EOC-prone conditions do not exist or have not been introduced as part of a plant change. Hence, a review of a plant change should look for situations where one or more of the following characteristics are introduced as a result of the change and thus should be corrected if possible.

- To deal with the 'bad information' interface, an analysis/review should at least look for those acts that operators may take that (a) would fail or otherwise make unavailable a PRA function or system, or (b) would reduce the accident mitigating redundancy available, or (c) would exacerbate an accident challenge, because the change has caused such an action to be performed on the basis of just one primary input/indication for which there is no redundant means to verify the true plant status. Such a situation identifies a vulnerable case where EOCs may likely be performed based on just one erroneous (failed, spurious, etc.) input such as an alarm, indicator, or verbal cue of an observed condition.

  In identifying such cases, one should keep in mind that multiple indications may use the same faulty input (e.g., subcooling margin indication and primary system indication may use the same pressure transmitter(s); multiple reactor vessel level indications may rely on the same power supply) and hence a single fault may actually affect multiple inputs observable to the operator. Depending on the how the failure affects the indications (fail high, low, mid-scale, etc.), the failure may not be "obvious" and a EOC-prone situation may exist that may need to be rectified.

- To deal with the procedure-training interface, an analysis/review should at least look for those acts that operators may take that (a) would fail a PRA function or system, or (b) would reduce the accident mitigating redundancy available, or (c) would exacerbate an accident challenge, because the change has caused the procedure (including entry conditions) and/or training guidance:

  - to become ambiguous/unclear (e.g., vague criteria as to when to abandon the main control room),

  - to introduce a repetitive situation in the response steps where a way to proceed out of the procedure and/or the specific repetitive steps is not evident (e.g., at the end of a series of steps, the procedure calls for a return to a previous step with no clear indication as to how the operators ultimately get out of the repetitive loop of steps,

  - to place the operators in dilemma conditions without some guidance/criteria as to how to "solve" the dilemma (e.g., being vague as to whether or not to shutdown a diesel with a cooling malfunction when all other ac power is unavailable),

  - to require the operators to rely on memory especially for complex or multi-step tasks, or

  - to require the operators to perform calculations or make other manual adjustments especially in time-sensitive situations.

The above identify vulnerable cases where EOCs may likely be performed because the procedures and/or training do not adequately cover accident situations that may be faced by the operator or rely on techniques (require memory or adjustments) that may be difficult to perform properly especially when in a dynamic response situation. In these cases, mismatches between the actual event response that is required and the procedure/training guidance can become magnified making conditions potentially more prone to EOCs.

8. REFERENCES

[1] *Use of Probabilistic Risk Assessment Methods in Nuclear Activities: Final Policy Statement*, Federal Register, Vol 60, p. 42622 (60FR 42622), US Nuclear Regulatory Commission, August 16, 1995.

[2] *Code of Federal Regulations 10, Parts 1 to 50*, Office of the Federal Register National Archives and Records Admission, Revised as of January 1, 2001.

[3] *An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Licensing Basis,* Regulatory Guide 1.174, Rev. 1, US Nuclear Regulatory Commission, November 2002.

[4] *An Approach for Determining The Technical Adequacy of Probabilistic Risk Assessment Results For Risk- Informed Activities*, Draft Regulatory Guide 1.200, U.S. Nuclear Regulatory Commission, February 2004.

[5] *Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications,* ASME RA-S-2002, American Society of Mechanical Engineers, April 5, 2002.

[6] *Probabilistic Risk Assessment Peer Review Process Guidance*, NEI 00-02 Revision A3, Nuclear Energy Institute, March 2000

[7] *Use of Probabilistic Risk Assessment in Plant-Specific, Risk-Informed Decisionmaking: General Guidance,* NUREG-0800, Chapter 19, Rev. 1, US Nuclear Regulatory Commission, November 2002.

[8] A.D. Swain and H.E. Guttmann, *Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Applications - Final Report,* NUREG/CR-1278, SAND80-0200, Sandia National Laboratories, August 1983.

[9] Embrey, D. E., et al., *SLIM-MAUD: An Approach to Assessing Human Error Probabilities Using Structured Expert Judgment (Vols. I & II),* NUREG/CR-3518, Brookhaven National Laboratory, Upton, NY, 1984.

[10] *Technical Basis and Implementation Guidelines for A Technique for Human Event Analysis (ATHEANA),* NUREG-1624, Rev. 1, US Nuclear Regulatory Commission, May 2000.

[11] *Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants,* NUREG-1150, US Nuclear Regulatory Commission, December 1990

[12] Alan D. Swain, *Accident Sequence Evaluation Program Human Reliability Analysis Procedure,* NUREG/CR-4772, SAND86-1996, Sandia National Laboratories, February 1987.

[13] *SHARP1 - A Revised Systematic Human Action Reliability Procedure,* EPRI NP-7183-SL, Electric Power Research Institute, December 1990.

[14] *SPAR-H Method,* NUREG/CR- later, INEEL/EXT-02-10307, Idaho National Engineering and Environmental Laboratory, DRAFT, November 2002.

[15] J. Reason, *Human Error,* Cambridge, England: Cambridge University Press, 1990 and *Managing the Risks of Organizational Accidents,* Aldershot, UK: Ashgate, 1997.

[16] D.D. Woods et. al., *Behind Human Error: Cognitive Systems, Computers, and Hindsight*, Crew System Ergonomics Information Analysis Center (CSERIAC), The Ohio State University, Wright-Patterson Air Force Base, Columbus, OH, December 1994.

[17] M.R. Endsley, *Towards a theory of situation awareness in dynamic systems,* Human Factors, 37, pp. 65-84, 1995.

ACKNOWLEDGMENTS

We would like to thank Gareth Parry and Susan Cooper of the USNRC for several thorough reviews of this document at various stages of it development and for many important comments and suggestions. Similarly, we would like to thank Dennis Bley of Buttonwood Consulting and Bruce Hallbert of INEEL for their reviews and comments.

APPENDIX A

Guidance on Consideration of Performance-Shaping Factors for Post-Initiator HFEs

The following provides more detail on the performance-shaping factors presented in Section 5.3.3.5, including some key characteristics to consider when assessing the influence of these performance-shaping factors on the failure probability for a human failure event (HFE). Included are important interactions among the factors that should also be examined when assessing the holistic impact of the performance-shaping factors on operator performance. These factors need to be assessed on a plant-specific and accident sequence-specific basis considering the relevant context and the act to be performed.

It is important to re-iterate that this Appendix is written for the specific purpose of addressing post-initiator HFEs in a risk assessment for commercial nuclear power plant operations occurring nominally at full power, and for internal initiating events. However, much of it is considered useful to other modes of operation and for other industry applications such as safety assessments of chemical plants, space mission risk assessments, and others. Similarly, much of it is considered applicable for external initiating events but it should be used with the additional context of such events in mind (e.g., shaking during a seismic event). Additionally, portions of this Appendix may be of benefit in examining human actions related to nuclear materials and safeguard types of applications.

Specific HRA methods and tools used by the industry may define and "measure" these performance-shaping factors somewhat differently than described here. That is, they may use a different explicit set of performance-shaping factors that 'roll-up' many of the factors listed below into the definitions of their specific factors (e.g., stress, workload). Nevertheless, these summaries are provided as one means with which to assess that the specific HRA method/tool has been used such that the characteristics described here have indeed been accounted for in the evaluation of post-initiator human error probabilities (HEPs).

While quantitative guidance is not provided (specific quantification depends on the method/tool that is used), the following should be useful in arriving at whether a performance-shaping factor, regardless of the method/tool, qualitatively is a weak/strong positive, neutral (or not applicable), or negative influence. The method/tool that is used, should have established scales and corresponding definitions for assessing each PSF qualitatively (e.g., "good', "adequate", "poor") and a way to interpret the result into a quantified HEP.

The performance-shaping factors are addressed below.

Applicability and suitability of training/experience. For both in-control room and local actions, this is an important factor in assessing operator performance. For the most part, in nuclear plants, operators can be considered "trained at some minimum level" to perform their desired tasks.

However, from a HRA perspective, the degree of familiarity with the type of sequences modeled in the PRA and the actions to be performed, can provide a negative or positive influence that should be assessed on the likelihood of operator success. In cases where the type of PRA sequence being examined or the actions to be taken are not periodically addressed in training (such as covered in classroom sessions or simulated every one to two years or even more often) or the actions are not performed as part of their normal experience or on-job duties, this factor should be treated as a negative influence. The converse would result in a positive influence on overall operator performance.

One should also attempt to identify systematic training biases that may affect operator performance either positively or negatively. For example, training guidance in a pressurized water reactor (PWR) may provide a reluctance to use "feed and bleed" in a situation where steam generator feed is expected to be recovered. Other biases may suggest operators are allowed to take certain actions before the procedural steps calling for those actions are reached, if the operators are sure the actions are needed. Such training "biases" could cause hesitation and hence higher HEPs for the desired actions, as in the first case above, or as in the case of not waiting to take obvious actions, be a positive influence.

It is incumbent on the analyst to ensure that training and/or experience is relevant to the PRA sequence situation and desired actions. The more it can be argued that the training is current, "is like the real event," is varied enough to represent differences in the way the event can evolve, and proficiency is demonstrated on a periodic basis, the more positive this factor. If there is little or no training/experience or there are potentially negative training biases for the PRA sequence being examined, this factor should be considered to have a negative influence.

Suitability of relevant procedures and administrative controls. For both in-control room and local actions, this is an important factor in assessing operator performance. Similar to training, for the most part, procedures exist to cover many types of sequences and operator actions.

However, from a HRA perspective, the degree the procedures clearly and unambiguously address the types of sequences modeled in the PRA and the actions to be performed, dictates whether they are a negative or positive influence on operator performance. Where procedures have characteristics like those below related to the desired actions for the sequences of interest, this factor should be considered a negative influence:

- ambiguous/unclear/non-detailed steps for the desired actions in the context of the sequence of interest,

- situations can exist where the operators are likely to have trouble identifying a way to proceed forward,

- there is a requirement to rely on considerable memory,

- operators must perform calculations or make other manual adjustments especially in time-sensitive situations,

- there is no procedure or the procedure is likely to not be available especially when taking local actions "in the heat of the scenario" and it cannot be argued that the desired task is simple and a "skill of the craft" or automatic/memorized activity that is trained on or there is routine experience.

Otherwise, this factor should be considered as adequate or even a positive influence.

Talk-throughs with operations and training staff can be helpful in uncovering ‘difficulties’ or ‘ease’ in using the relevant procedures considering the associated training that the operators receive and the way the operators interpret the use of the procedures.

Availability and clarity of instrumentation (cues to take actions as well as confirm expected plant response). For both in-control room and local actions, this is an important factor since operators, other than for immediate and memorized response actions, take actions based on diagnostic indications and look for expected plant responses to dictate follow-on actions. For in-control room situations, typical nuclear plant control rooms have sufficient redundancy and diversity for most important plant parameters. For this reason, most HRA methods inherently assume that adequate instrumentation typically exists. Nevertheless, this should be verified looking for the following characteristics that could make this a negative performance-shaping factor, particularly in situations where there is little redundancy in the instrumentation associated with the act(s) of interest:

- the key instrumentation associated with an act is adversely affected by the initiating event or subsequent equipment failure (e.g., loss of DC power causing loss of some indications, spurious or failed as a result of a hot short from a fire)

- the key instrumentation is not readily available and may not be typically scanned such as on an obscure back panel

- the instrumentation could be misunderstood or may be ambiguous because it is not a direct indication of the equipment status (e.g., PORV position is really the position of the solenoid valve and not the PORV itself)

- the instrumentation is operating under conditions for which it is not appropriate (e.g., calibrated for normal power conditions as opposed to shutdown conditions)

- there are so many simultaneous changing indications and alarms or the indication is so subtle, particularly when the time to act is short, it may be difficult to “see and pick out” the important cue in time (e.g., a changing open-close light for a valve without a concurrent alarm or other indication, finding one alarm light among hundreds).

The above also applies to local actions outside the control room, recognizing that in some situations, less instrumentation may exist (e.g., only one division of instrumentation and limited device actuators on the remote shutdown panel). However, on the positive side, local action indications often can include actual/physical observation of the equipment (e.g., pump is running, valve stem shows it is closed) that compensates for any lack of other indicators or alarms.

It is incumbent on the analyst to ensure that adequate instrumentation is available and clear so that the operators will know the status of the plant and when certain actions need to be taken.

Time available and time required to complete the act, including the impact of concurrent and competing activities. This can be an important influence for both in-control room and local actions since clearly, if there is not enough or barely enough time to act, the estimated HEP is expected to be quite high. Conversely, if the time available far exceeds the time required and there are not multiple competing tasks, the estimated HEP is not expected to be strongly influenced by this factor.

It is important that the time available and the time needed to perform the act be considered *in concert with* many of the other performance-shaping factors and the demands of the sequence. This is because the thermal-hydraulic inputs (e.g., time to steam generator dryout, time to start uncovering the core), while important, are not the only influences. (Note, it is best if the thermal-hydraulic influences are derived from plant-specific or similar analyses rather than simple judgments).

The time to perform the act, in particular, is a function of the number of available staff, the clarity and repetitiveness of the cues that the act needs to be performed, the HMI, the complexity involved (discussed later), the need to get special tools or clothing (discussed later), consideration of diversions and other concurrent requirements (discussed later), where in the procedures the steps for the act of interest are called out, crew characteristics such as whether the crews are generally aggressive or slow and methodical in getting through the procedural steps, and other potential 'time sinks'.

Clearly there is judgment involved, but as described here, it is not as simple as watching an operator perform an act in ideal conditions with a stop watch to determine the time required to perform the act. Only when the sequence context is considered holistically with the interfacing performance-shaping factors that have been mentioned here, can more meaningful "times" be estimated. Hence, especially for complex acts and/or situations, walkdowns and simulations can be helpful in ensuring overly optimistic "times" have not been estimated. Whatever HRA method/tool is used, determination of these times should include the considerations provided here.

Complexity of required response along with workload, time pressure, the need for special sequencing, and the familiarity of the situation. This is one of those catch-all type factors that attempts to measure the overall complexity involved for the situation at hand and for the act itself (e.g., many steps have to be performed by the same operator in rapid succession vs. one simple skill-of-the craft action). Many of the other performance-shaping factors address elements of the overall complexity such as the need to decipher numerous indications and alarms, many and complicated steps in a procedure, poor HMI, etc. Nevertheless, this factor should also capture 'measures' such as the ambiguity of the task, the degree of mental effort or knowledge involved, whether this is a multi-variable or single variable associated task, the overall task load and time pressure on the operators, whether special sequencing is required in order for the act to be successful especially if it involves multiple persons in different locations, whether the activity may require very sensitive and careful manipulations by the operator, etc. The more these "measures" describe an overall complex situation, this performance-shaping factor should be found to be a negative influence. To the extent these "measures" suggest a simple, straightforward, unambiguous process, this factor should be found to be nominal or even ideal (i.e., positive influence).

Team/crew dynamics and crew characteristics (degree of independence among individuals, operator attitudes - biases - rules, use of status checks, approach for implementing procedures, e.g., aggressive vs. slow and methodical crew). This is another catch-all type of factor which can be important particularly to in-control room actions where the early responses to an event occur and the overall strategy for dealing with the event develops. In particular, the way the procedures are written and what is (or is not) emphasized in training (may be related to an organization influence), can cause systematic and nearly homogeneous biases and attitudes in most or all the crews that can affect overall crew performance. A review of this factor should include looking for such characteristics as:

- are independent actions encouraged or discouraged among crew members (allowing independent actions may shorten response time but could cause inappropriate actions going unnoticed until much later in the scenario)

- are there common biases or 'informal rules' such as a reluctance to do certain acts, whether the overall philosophy is to protect equipment or run it to destruction if necessary, or the way procedural steps are interpreted

- are periodic status checks performed (or not) by most crews so that everyone has a chance to 'get on the same page' and allow for checking what has been performed to ensure the desired activities have taken place

- is the overall approach of most crews to aggressively respond to the event, including taking allowed shortcuts through the procedural steps (which will shorten response times), or are typical responses slow and methodical (we trust the procedures type of attitude) thereby tending to slow down response times but making it less likely to make mistakes.

Observing simulations and using talk-throughs and walkdowns can provide valuable insights into the overall crew response dynamics, attitudes, and the typical times it takes them to get through various procedure steps and deal with unexpected failures or distractions. This knowledge can be a key input into the HEP evaluation including determining the typical time to respond (see that factor above).

Consideration of 'realistic' accident sequence diversions and deviations (e.g., extraneous alarms, outside discussions, the sequence evolution is not exactly like that trained on...). Particularly for in-control room actions where the early responses to an event occur and the overall strategy for dealing with the event develops, this can be an important factor to be considered. Through simulations, training, and the way the procedures are written, operators 'build up' some sense of expectations as to how various types of sequences are likely to proceed; even to the extent of recognizing alarm and indication patterns and what actions will likely be appropriate. To the extent the actual sequence may not be 'just like in the simulator,' such as involving other unimportant or spurious alarms, the need for outside discussions with other staff or even offsite entities such as a fire department, differences in the timing of the failed events, and behavior of critical parameters, etc., all can add to the potential diversions and distractions that may delay response timing or in the extreme, even confuse the operators as to the appropriate actions to take.

Hence the 'signature' of the PRA accident sequence and the potential acts of interest should be examined against the expectations of the operators to determine if there is a considerable potential for such distractions and deviations. Observing simulations and talking with the operators can help in discovering such possibilities. This could impact the HEP mean value estimate as well as the uncertainty in the HEP, which may be important to assessing the potential risk or in establishing the limits for doing sensitivity studies with the HEP.

Available staffing/resources. For in-control room actions, this is generally not an important consideration (i.e., not a particularly positive or negative factor) since plants are supposed to maintain an assigned minimum crew with the appropriate qualified staff available in or very near the control room.

However, for ex-control room local actions, this can be an important consideration particularly dependent on (a) the number and locations of the necessary actions, (b) the overall complexity of the actions that are required to be taken, and (c) the time available to take the actions and the time required to perform the actions (see above for more on these related factors). For instance, where the number of actions are few and complexity is low and time available is high, one or two personnel available to perform the local actions may be more than enough and thus the available staffing can be considered to be adequate or even a positive factor. On the other hand, where the number of actions and their complexity is high, and with little time, perhaps three or more staff may be necessary. Additionally, the time of the day the initiating event occurs may be a factor since typically, night and graveyard shifts have fewer people available than the day shift (see more on this particular factor, below).

It is incumbent on the analyst to demonstrate that the available staffing is sufficient to perform the desired actions and/or assess the HEP(s) accordingly.

Human-machine interface (HMI). This is generally not an important factor relative to in-control actions since, given the many control room design reviews and improvements and the daily familiarity of the control room boards and layout, problematic human-machine interfaces have been taken care of or are easily worked around by the operating crew. Of course, any known very poor human-machine interface should be considered as a negative influence for an applicable action even in the control room. For example, if common workarounds are known to exist that may negatively influence a desired act, this should be accounted for in the HEP evaluation. Furthermore, it is possible that some unique situations may render certain human-machine interfaces less appropriate and for such sequences, the relevant interfaces should be examined.

However, since local actions may involve more varied (and not particularly human-factored) layouts and require operators to take actions in much less familiar surroundings and situations, any problematic human-machine interfaces can be an important negative factor on operator success. For instance, if to reach a valve to open it manually requires the operator to climb over pipes and turn the valve with a tool while in a laid out position, or in-field labeling of equipment is generally in poor condition and could lengthen the time to find the equipment, etc., such 'less ideal' human-machine interfaces could mean this is a negative performance-shaping factor. Otherwise, if a review reveals no such problematic interfaces for the act(s) of interest, this influence can be considered adequate or even positive.

Walkdowns and field or simulator observations can be useful tools in discovering problems (if any exist) in the human-machine interface for the actions of interest. Sometimes, discussions with the operators will reveal their own concerns about issues in this area.

Environment in which the act needs to be performed. Except for relatively rare situations, this factor is not particularly relevant to in-control room actions given the habitability control of such rooms and the rare challenges to that habitability (e.g., control room fire, loss of control room ventilation, less lighting as a result of station blackout). However, for local actions, this could be an important influence on the operator performance. Radiation, lighting, temperature, humidity, noise level, smoke, toxic gas, even weather for outside activities (e.g., having to go on a potential snow-covered roof to reach the atmospheric dump valve isolation valve), etc., can be varied and far less than ideal. Hence any HEP assessment should ensure that the influence of the environment where the act(s) needs to take place is accounted for as a performance-shaping factor. This factor may be non-problematic (adequate) or a negative influence (even to the point of not being able to perform the act).

Accessability and operability of the equipment to be manipulated. As with the environment factor, this factor is not particularly relevant most of the time to in-control room actions except for special circumstances such as loss of operability of indications or controls as a result of the initiator or equipment failures (e.g., loss of DC). However, for local actions, accessability and the operability of the equipment to be manipulated may not always be ensured, and needs to be assessed in the context with such influences as the environment, the need to use special equipment (discussed later), and HMI. Hence any HEP assessment should ensure that this factor, for where the act(s) needs to take place, is accounted for as a performance-shaping factor. This factor may be non-problematic (adequate) or a negative influence (even to the point of not being able to perform the act).

The need for special tools (keys, ladders, hoses, clothing such as to enter a radiation area...). As for the environment and accessability factors, this factor is not particularly relevant to in-control room actions with the common exception of needing keys to manipulate certain control board switches or similar controls (e.g., key for explosive valves for standby liquid control injection in a BWR). However, for local actions, such needs may be more commonplace and necessary in order to successfully perform the desired act. If such equipment is needed, it should be ensured that the equipment is readily available, its location is readily known, and it is either easy to use or periodic training is provided, in order for this factor to be considered to be positive or adequate. Otherwise, this factor should be considered to have a negative influence on the operator performance, perhaps even to the point of making the failure of the desired action very high.

Communications (strategy and coordination) as well as whether one can be easily heard). For in-control room actions, this factor is not particularly relevant although there should be verification that the strategy for communicating in the control room is one that tends to ensure that directives are not easily misunderstood (e.g., it is required that the board operator repeat the act to be performed and then wait for confirmation before taking the act). Generally, it is expected that this will not be problematic; but any potential problems in this area (such as having to talk with special air packs and masks on in the control room in a minor fire) should be accounted for if they exist.

For local actions, this factor may be much more important because of the possible less than ideal environment or situation. It should be assured that the initiating event (e.g., loss of power, fire, seismic) or subsequent equipment faults are not likely to negatively affect the ability for operators to communicate as necessary to perform the desired act(s). For instance, having to set-up the equipment and talk over significant background noise and possibly having to repeat oneself many times should be a consideration - even if just as a possible 'time sink' for the time to perform the act. Additionally, there should be training on the use of the communication equipment, its location is readily known, and its operability periodically demonstrated and shown to be in good working condition. Depending on the status of these characteristics, this factor may be non-problematic (adequate) or a negative influence (even to the point of not being able to perform the act).

Special fitness needs: While typically not an issue for in-control room actions, this could be an important factor for a few local actions depending on the specific activity involved. Having to climb up or over equipment to reach a device, needing to move and connect hoses, using an especially heavy or awkward tool, are examples of where this factor could have some influence on the operator performance. In particular, the response time for an action may be increased for successful performance of the act. Physically demanding (or not) activities should be considered in the evaluation of any HEP where it is appropriate to do so. Talk-throughs or field observations of the activities involved can help determine whether such issues are relevant to a particular HFE.

Time of day: While it is recognized that time of day and similar influences such as day of shift can affect the bio-rhythm of personnel and potentially their performance, not much is understood on how to quantify such effects. Moreover, it is typically the PRA's intent to measure an average risk for the whole year, as opposed to at a specific point in time. For these reasons, time of day is not typically specifically treated in a HEP evaluation.

However, at least one easily measurable effect of the time of day is on the available level of staffing during the early stages of a transient response (see available staffing factor above). Especially if there are significant differences in the staffing levels depending on the time of day, it is advisable to either treat the staffing level in a HEP evaluation as the minimum available depending on the shift, or probabilistically account for these aleatory differences more explicitly in the PRA model.

ELSEVIER

Available online at www.sciencedirect.com
SCIENCE DIRECT•

Reliability Engineering and System Safety 83 (2004) 129–138

RELIABILITY ENGINEERING & SYSTEM SAFETY

www.elsevier.com/locate/ress

On the way to assess errors of commission

Oliver Sträter*, Vinh Dang, Barry Kaufer, Ardela Daniels

EUROCONTROL, Human Factors and Management Unit (DIS-HUM), Rue de la Fusee 96, B-1130 Bruxelles, USA

Abstract

In January 2002, the OECD-NEA (Organization for the Economic Cooperation and Development, Nuclear Energy Agency) Working Group Risk (WGRISK) held a workshop at on Human Reliability data needs and potential solutions. The workshop was initiated to exchange the possibilities to proceed in the area of assessing errors of commission, those interventions of operators that are not required from the system point of view and aggravate the scenario evolution. A common sense in the research on errors of commission is that the respective HRA methods require a more profound database than the classical HRA methods.

This paper summarizes the discussion of the workshop. It discusses the various data sources and their use in HRA, the problems that make it difficult to get appropriate data for HRA, and possible approaches to overcome this bottleneck in HRA.

Keywords: Human performance; Human reliability analysis; Scenario analysis; Interdisciplinary analysis; Integrated human performance modeling; Safety management; Knowledge management

1. Introduction

One of the important fields of Human Reliability Assessment (HRA) is the data used for assessment. Any method needs data as well as any data needs an underlying model to structure it and therefore to get a systematic approach in the observations.

1.1. Models and data

There are two possibilities for the coherency of a model and observations. If the observations fit to the model, we certainly do not notice any problem and think the model (and the data) is correct. What happens if a model and observations disagree? If there is a mismatch, we have several possibilities: rejection of the difference (mostly done by ignoring the observations), reluctant acceptance of the difference or systematic evaluation of the disagreement (Fig. 1).

Problems occur every time this cycle is not working either because the technical feasibility is not yet given or organizational reluctance to approach the gap lead to deviations in retrospective observations and predictive models.

Errors of commission have been such a gap in the last decades. The TMI accident of 1979 showed the relevance of these errors for system safety as well as several other serious events did. Surely there was a gap between what the HRA methods could predict (and prevent) and what the operational experience showed regarding relevant human error mechanisms as well as organizational and contextual influences. So called 1st generation HRA methods (like THERP, ASEP, HCR, etc.) were proven by such experience as not offering sufficient prevention.

The reasons that 1st generation HRA methods cannot cover these errors are manifold and there is no sweeping answer. Depending on the method one can find one or more of the following aspects lacking:

- An appropriate methodological framework, which allows to identify and represent the relevant error-mechanisms as well as contextual and organizational conditions.
- An appropriate representation of the error-mechanisms as well as contextual and organizational conditions in the quantification approach, dependency model or density distribution.
- A sufficient database for the quantification of the error-mechanisms as well as contextual and organizational conditions.

If one looks at plant experience, errors of commission can occur not only in serious events (like TMI, Davis Besse or Chernobyl) but they also occur in more 'daily' events. Their possible relevance for safety is therefore present

[*] Corresponding author. Tel.: +32-2-729-5054; fax: +32-2-729-9149. *E-mail address:* oliver.straeter@eurocontrol.int (O. Sträter).

0951-8320/$ - see front matter © 2003 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ress.2003.09.004

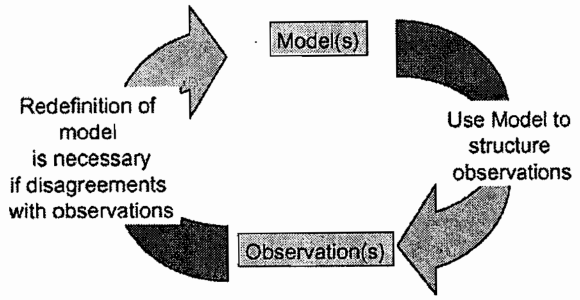

Model(s)
Use Model to structure observations
Observation(s)
Redefinition of model is necessary if disagreements with observations

Fig. 1. Model-Observation loop for behavioral and scientific progress.

though serious events are thankfully lacking. Nevertheless their systematic and thorough treatment in HRA methods is pending.

Contrasting these observations with what could be done with 1st generation HRA methods led to the development of the so-called 2nd generation HRA methods. They extend the scope of HRA to a better representation of human error mechanisms, contextual conditions and organizational aspects and by this to the prediction of errors of commission. A discussion of the differences between 1st and 2nd generation HRA methods can be found in Ref. [1].

A couple of problems arise when speaking about errors of commission. The first problem is that these errors are, from the behavioral point of view, not errors in the sense that a person failed to perform correctly. Operators making an 'error of commission' usually perform correctly from their current understanding of the system, the system behavior and future system process. However, the system is in a state where this behavior with the correct intention is not appropriate. The system-state is different to the one assumed by the operator for instance. Two major aspects of errors of commission arise from this mismatch of operators' behavior and the system-state:

- Context, as the description of those aspects of the system state that makes the operator conclude that his behavior is correct, is one of the most important issues for understanding and tackling errors of commission.
- The term error is, if at all, only appropriate from the point of view of the behavior of the technical system. The term specifies that the system performs outside a given specification due to actions of operators that were based on the intention to achieve a correct system behavior.

Both aspects lead to a tension between engineering demands of mathematical calculus (how to get Human Error Probabilities from the observations) and demands of human science (what are the invariant aspects leading to such a human behavior). It is generally difficult to solve the contradiction that the same human action can be understood as error-free behavior from the human science perspective but as an error from the system point of view. This tension is based on various viewpoints one can have regarding the issue of errors of commission:

- Viewpoint of descriptive correctness: Quantification of human actions in a mathematical sense is in principle not reasonable, because the quantitative figure requires a precise estimation about the numbers of errors *and* about the numbers of opportunities. Since neither the number of opportunities can be precisely assessed, nor the number of errors, quantification is not useful, analysis has to focus on the correct qualitative representation of the human behavior.
- Viewpoint of methodological correctness: Human errors are only assessable by using models that only can converge to statistical and descriptive correctness since the number of errors and the number of demands are always fuzzy.
- Viewpoint of statistical correctness: Human errors have to obey the statistical exactness that the formula of HEP (Human Error Probability) defines and has to be calculated exactly as errors per demands.

Much progress has been made in the last years on how to approach the issue of errors of commission (summaries in Refs. [2,3]). The methods and approaches developed can be distinguished into more data-driven approaches (investigation of operational data, experimental studies) and more methodological-driven approaches (search schemes, frameworks). Both have in common that the general principle outlined in Fig. 1 for achieving progress in methodological development and operational event-investigations hold for both, but with a different starting point (model vs. observation).

1.2. HRA data exchange

A number of other activities within the OECD member countries showed that an international effort to harmonize the thinking about safety issues can lead to a successful further development of the methods used. There is for instance a common cause database of the OECD or the incident reporting system (IRS) of OECD and IAEA [4–7]. However, there is a certain danger that a particular Human Reliability Database may also narrow the potentials of finding new safety issues not reflected in the observations yet.

Nevertheless, the activities in other fields showed that there is a good reason to consider HRA data exchange. Even the building process itself helps aligning the practical needs with the scientific ones (i.e. predictive model vs. observed information). It reduces the gap between scientific thinking and the way the methods are applied in the plants.

The OECD/NEA Working Group on Risk Assessment created a task on errors of commission to exchange ideas and approaches and to start the process indicated by Fig. 1. A three-year working task was started in 1997 and two workshops were held in 2001 (Washington) and 2002 (Munich). This paper gives a short overview of the discussions during the workshop held in Munich January 2002 [2,3,8]. The workshop objectives were:

- What are the data needs in PSA/HRA?
- How can data be generated?
- Do we need systematic data exchange?
- Do we need an HRA database?

A number of experts participated in the workshop (see acknowledgements). The comments and statements as follows are based on the common work performed during the workshop. The discussion could be structured into three main areas: Embedding of HRA in the PSA and regulation, the invariance in HRA, and future considerations for HRA.

2. Embedding of HRA in the PSA and regulation

2.1. From relations to requirements

Probabilistic Safety Assessment (PSA), and therefore also HRA, has been strongly influenced by regulatory requirements. HRA feeds this regulatory purpose with human reliability methods and data. Therefore any HRA data exchange needs to meet one important objective of HRA, namely quantification. This, however, does not mean necessarily that an HRA database has to contain figures. As examples in the past show, this may even hinder the efficient exploitation of the information for other methods than the one underlying the data collection and data structure. For the sake of data exchange, it is even more important that it contains information that provides input for the development and improvement of existing and planned HRA models. Transferability of the knowledge contained in the database will be an essential factor for its success.

Any activity resulting in an HRA database therefore needs to clarify the most relevant regulatory requirements in order to review them related to HRA. A basic question for the success of such an activity is whether an HRA-data exchange can help the utility and regulator with their requirements. However, these requirements are often neither explicit nor are they known completely. Fig. 2 represents the different parties and possible relations to other parties.

Regulators are certainly related to the utilities and their plants. Science (including HRA developers) is an important driver for keeping safety assessments at the state of the art and to achieve progress in new safety relevant areas. Finally the public (and society) are important external drivers as well as clients of safety assessments. A current social driver is, for instance, the increasing age of the population that leads-in combination with the increased use of computer technology-to considerable changes in working conditions. Replacements for retired workers in a comparable old-fashioned technology like a nuclear power plant are therefore difficult to get [9–11]. As a client, the population finally agrees or disagrees to the safety level achieved by safety assessments and can either support or, in the other extreme, terminate the entire industry.

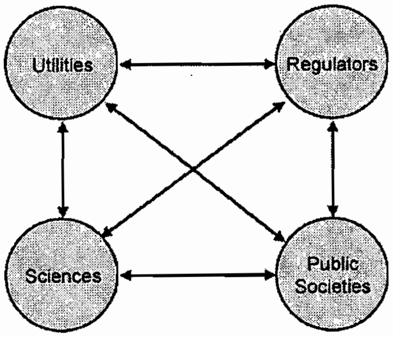


Fig. 2. Different relations of the parties to be considered in the probabilistic safety assessment.

Certainly each party does not reflect a homogeneous organization with a common understanding of the issue but even the simplified relations show clearly that not all probably seek for the accomplishment of common goals. These differences also have an impact on what is expected from HRA and what to be expected from an HRA data exchange.

The tension between utilities and regulator, for instance, makes the collection of plant specific data difficult. Strategies have to be built up to make the collection of data attractive for a utility though they may be also used for regulatory purposes. Such strategies are ideally based on the role of HRA data in the entire framework represented in Fig. 2.

2.2. Role of HRA data and methods

The context outlined in the previous chapter has an impact on the requirements of any HRA data exchange:

- To define the purpose(s) of the analysis, it has to be identified who will be the end user of an analysis: Utility, regulator, scientist, or public.
- The selection of the quantification model must match the purpose(s) of the analysis of HRA
- Any HRA data exchange must reflect the needs of the respective HRA quantification model(s)

2.3. Use of HRA data

Any HRA task happening in the interrelation of one of the parties involved in Fig. 2 would require an information exchange regarding operating experience, methodological concepts, scientific developments or public opinions.

According to the different parties involved in a safety assessment, HRA may have different meanings and different objectives. For users of a PSA/HRA quantification some objectives are that the data and the method are accessible, that they are simple to apply, and that the results are repeatable. For HRA developers the correctness and completeness in terms of correct representation of the complexity of the situation to be assessed, the richness of possible human behavior, and the uniqueness of the contextual specificity of a situation to be assessed. Finally, reviewers or regulators need repeatable results in order to be able to generate a basis for comparisons between different plants or different countries.

Consequently, the meanings of HRA may differ depending on the intended use. This also has an impact on the need to collect relevant raw information because the definition of relevance also differs with the intended use.

Despite all the differences, it is relatively easy to exploit qualitative insights of other methods or databases for own development. This possibility provides a clear hint that there is a common underlying model of performance, though the structure and contents of methods may differ and consensus has not yet been achieved on such a model.

Up to now most discussions are focussing on the differences between the models more than on the commonalties. Therefore the discussion about which information should be contained in a database may not find a strong consensus. A step forward is to come up with a set of 'neutral' (i.e. method independent) frameworks and taxonomies (e.g. for PSFs, causes, and error modes).

Such a neutral approach could be realized in a several ways. To get an idea, several types of exchange approaches were developed in the past or are currently under development. Those can be distinguished into the following principal approaches (additional discussions in [1]):

- Taxonomy related approaches: Structured and easy to use by a wide scope of potential users but restricted if the issues observable in an event are not covered by the taxonomy used.
- Structure related approaches: These approaches are a mixture between open text and taxonomy. They are able to provide information beyond what is coded in a taxonomy and are fairly easy to use. Structured approaches accept and code all sorts of information and data.
- Open text approaches: allow description of the full richness of an event and is flexible to react on new human reliability issues coming up in an event. An example is the Incident Reporting System (IRS).

3. Invariance in HRA

Independent from the intended use, some aspects of any HRA are invariant. These invariant aspects are represented in Fig. 3.

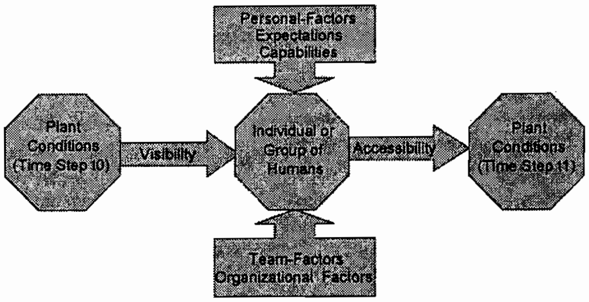


Fig. 3. Invariant aspects driving human interventions on plant conditions

Any HRA assumes that an individual or group of humans 'links' a certain plant condition given at a time t_0 with a certain plant condition given at a time t_1 as an effect of the preceding conditions (of the plant and the group of humans). Every human action is conditioned by the personal factors of the person(s) as well as the expectations and capabilities of the person(s). Additionally, the embedding of the person in the team and organization is important to consider for the prediction of a possible action. On the side of the working environment the visibility of signals and the accessibility of controls are essential for successful achievement of a certain diagnosis or action. Note that this general model finally also holds for management and organizational influences on the plant. These invariant aspects are often called 'context'. HRA should specify the serious, safety significant context. Identifying these patterns is essential for safety and finally has the potential to save lives.

Various instances of this general model of aspects have been developed over the last years. Independent from the method one may have in mind, the following questions have not found a common denominator:

- Which conditions result in which cognitive behavior?
- Which PSFs are important?
- What is the degree of dependency among PSFs and how can it be assessed (dependencies between human performance and system or human and human or human and contextual aspects, etc.)?
- How is the relationship of contextual conditions (linear or rather non-linear)?
- What is the correct error taxonomy for Human Error and failure modes (especially if new technologies like advanced Instrumentation and Control are deployed in the plants)?
- Is it possible to understand human performance failures?
- Which malfunction or failure introduces undefined tasks and therefore potentials for errors of commission?
- What are the expected operator responses and corresponding failure modes?

Looking at such questions may lead to the conclusion that it is not feasible to identify a reasonable set of characteristics that could practically form a basis for specifying a 'Human Error' database. Finally one may conclude that the HRA community will never manage to agree on a common model of human performance. On the other hand, this is not needed to achieve progress. More important is a robust data set that can be mapped to many various models.

A first step in this direction is to think about what drives a HEP.

The various HRA quantification methods assume in their quantification model certain relationships of reliability to external circumstances. Basic approaches are:

- Task and activity related approaches: They assume that the equipment or components to be operated and controlled, like valves or diesels for instance, mainly drive a failure probability.
- Condition related approaches assume that a certain property of the task and activity drive a failure probability like the ergonomic layout of switches in the control room, the organizational set-up of the work or the constraints of the situation (time or others).
- Cognition related approaches that assume that the demand of a certain cognitive activity drives the failure probability like monitoring, coordinating etc.

Unless the questions mentioned in this section are solved, no clear decision can be made on the best and most valid approach. However, science provides HRA with hints whether a certain way of assessment makes scientific sense or not. These aspects can be further broken down into five invariant aspects that are described below.

3.1. The idea of intransitive statements

Basically the quality of a quantification method can be assessed based on the number of transitive statements it has in its distributions (Straeter, in this paper).

Data can be transitive or intransitive. If, as a small example, it is observed in plant A that operators make more errors under time stress while operators of plant B make less errors under time stress, the construct 'time constrain leads to more errors' is intransitive. Once an intransitive statement is observed, the underlying construct of the observation is definitely proven as wrong (falsified). Therefore the idea of intransitive statements allows judging whether the approach 'Omitting a step in a procedure' is a sufficient representation of the reliability of a human action. According to the model-observation loop represented in Fig. 1, one has to think about redefining the model so that it is coherent with the observations, i.e. it has to be searched for those aspects making the observation transitive.

Any other way is not according to scientific criteria and is leading to wrong assessments with wrong safety implications for the plants and inappropriate means for improving safety.

A shared database may help to find such intransitive statements and by this to complete the 'puzzle' of HRA. Maybe, in the long term, one can identify common indicators for human performance and put uncertainties or differences into the distributions of these common indicators.

The idea of intransitive statements as a basis to proceed would also allow defining a couple of success criteria for important features of a HRA data exchange like:

- Coherency of field data (operational experience), expert judgement and experimental data: A database allows to conclude based on comparisons between various data sources whether a certain approach for the quantification is in principle stable or not. As a consequence, the HRA database in mind here is not containing quantitative figures but only frequencies of observations that allow checking transitiveness of the bases for quantification. Herewith experimental findings or effects observed in experiments can systematically be included into HRA. Overall it would provide effective use of various data sources and would limit uncertainties in expert ratings.
- Rare limited event situations: The events, HRA addresses are rare and therefore statistics are difficult. An exchange of data would increase the bases for a better estimation of the importance of a certain condition or a certain human property.
- Differences of NPP personnel and other industrial personnel: In many cases it would be desirable to transfer HRA experiences from other industries into nuclear settings. Such transfer could for instance provide ideas of how people react in life threatening situations that are (thankfully) too rare in nuclear to built a good statistic. A transfer of HRA experience would be acceptable if the transitive statements in the construct used are minimal.
- Extension of the data: HRA could make use of non-traditional data from nuclear plants like quality assessments (QA), audits, performance data etc. This option is important if one extends the view of HRA into the quantification of organizational aspects and safety culture. Also other fields like HRA for design-errors can be approached because experiences from HMI experiments can be exploited for new instrumentation and control systems in nuclear facilities.
- Support the designers of experiments: Designers of experimental studies could use such a repository to either optimize the effects to be investigated during an experiment or to set the criteria for screening useful data. A systematic data exchange regarding human performance would help for instance to identify points where human performance is to be measured (freezing points) or to define those systems faults that may lead to unintended performance. Herewith simulator studies could more efficiently recommend changing, selecting or creating HEPs. This approach can also serve as a way of cooperation between experimental set-up and evaluations of operational experience. As an example, this has been done very effectively in a small-scale investigation of communication errors in nuclear settings

in Refs. [12,13]. Communication errors observed in operational experience were taken to build up hypotheses for an experimental setting and to define the most probable effects of cognitive demands on communication quality.

- Judge about the correctness to transfer data from 'daily' events and experiments to the emergencies that are usually assessed in HRA: Usually HRA is dealing with rare events threatening human cognitive and emotional abilities. A question of concern is always whether the data from 'daily' events can be used to assess behavior in events that HRA is concerned with (i.e. live or at least job threatening events). Also experiments, though simulating such threatening events, cannot simulate the fear of real and serious consequences that would have to be expected in live situation. Data exchange would enable better judgement about such transfers from observed to speculative behavior by using the idea of transitivity. Also threatening situations from other industries, where accidents are unfortunately more frequent (like aviation) could be used to understand better the differences between 'daily' and 'threatening' events. Experiences with the developments of the methods are showing both, aspects that can be taken over as well as aspects that cannot be transferred (e.g. [1,14]).

3.2. The way of assessment

A second invariant aspect in HRA, which can be derived from Fig. 3, is the principal way of assessment. Fig. 4 outlines the principal steps for assessment: Conditions, human properties, behavior and effect (on the technical system).This way certainly has a couple of instances how to 'walk the way of assessment'. For instance, method xy entitles the conditions as PSFs (Performance Shaping Factors), the human properties as error mechanisms, the behavior as an unsafe act, and the effect as a human failure event. Another method *yz* may be reluctant to use the term error and therefore uses another terminology for this stage in the way of assessment. A third method *xz* may distinguish human properties further into cognitive aspects and biases. A different method may finally merge human properties and behavior to keep the assessment simple. All the methods known in the field of HRA come from different perspectives, different cultural environments and different constrains in the development. However, they are also consistent in their basic principles. The differences allow that the different HRA methods can learn form each other. Despite all differences, Fig. 4 indicated that there is a way and a use of shared information in order to enhance the further development of each method. The performance conditions used in various methods may hold as an example for the possibilities of a shared use of experiences: THERP, CREAM, ATHEANA, SPAR, CAHR or others are using quite different conditions for the reliability of human behavior. Sometimes they even use a different term for the conditions like PSFs (Performance Shaping Factors) or CPCs (Common Performance Conditions). However, a comparison of the conditions modeled gives insights into the completeness of the methods and the potential for further development. Overall it is a useful comparison to find out what is modeled differently in the various methods, like:

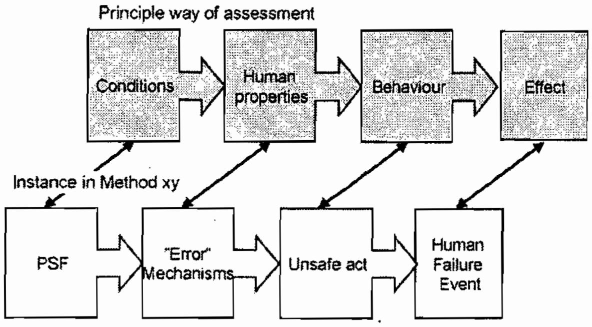


Fig. 4. Principle process of assessment and principle units of analysis in HRA.

- What are boundary conditions for human actions?
- What are the factors dominating the risk?
- What is focus/purpose of analysis?
- Can dependencies among conditions change over the course of an event?
- What specific way is used within the principle approach as represented in Fig. 4 (Human Failure Events, Unrequired Action, etc.)?
- Which steps through the principle approach lead to the optimal (i.e. minimal intransitive) way through the process? Is it simply *conditions/context* → *effects* relation or *conditions* → *cognition* → *effects* or others?

3.3. The use of HRA

The HRA process and method also has to fit to the user needs of persons performing HRA somewhere. According to a WANO-PC survey from 2001 on HRA practices, only 69% of the plants conducted a plant specific HRA for a PSA. In particular this tends to be the case in small countries or countries not perceiving a decreasing 'safety level' (WANO-Survey on Human Performance Practices in the Paris Center Region). This result shows that HRA methods and processes have not reached the final user or client of the development especially in those utilities with economic constrains where HRA is not paying off.

A probable reason for this is that the methods may probably not fit with the needs and constraints the HRA assessor in a plant has (like time constrains in the daily work, practicability and understandability of the method, availability of specific data, validity of the data available, economic use).

Such problems also have an impact on the success of a data exchange in the field of HRA, because the plants are important providers of the data (beside experimenters and operational experience). Another issue of HRA is that it does not fit to the industry needs. Transparency, guidelines, and standards are lacking so that HRA-analyses are frequently outsourced to specialists.

On the other hand many activities are going on in the plants as well as in the regulatory body where the HRA data exchange can be linked to. Basically any party producing data (plants, experimenters, regulatory bodies) stores new data into some kind of database. However, these databases do not have a 'common language' or not even a 'translator' between different solutions.

Whether the utilities will provide the necessary information for developers or specialists to understand the cognitive behaviors involved in the observations will, for instance, strongly depend on the gain the utilities will have from this activity [15]. Potential gains are for instance:

- More realistic assessments and therefore better use of HRA/PSA in the operational improvements (which in turn will improve the productivity of a plant).
- Better assessment of human contributions and therefore a more efficient relationship with the regulators (which reduces the efforts to be put into PSA by the plants).
- Exploitation of the data for uses other than HRA like defining training issues, procedural improvements, or the introduction of new systems.
- Avoiding unnecessary conservatism in safety assessments.
- Reduced costs and manpower effort in the entire PSA process.

Compared to the costs and effort lost in cumbersome discussions on these questions, the effort for creating a 'common language' or HRA data exchange will certainly payoff very soon. Some kind of marketing would help to raise the awareness of these advantages.

3.4. The sharing of information

Usually results of an HRA are shared by others parties of the community. This can be done on a voluntary basis (e.g. co-operations, conferences) or as a part of requirements in the regulatory process (regulatory assessments). Sharing information is part in these usual activities in order to avoid arguments about expert judgements in HRA and for comparing the safety issues and to learn from one another.

A common goal of HRA practitioners is therefore to achieve a result that is traceable, can be reviewed and is solid in its scientific grounds. Obviously, a data exchange facilitates these daily tasks of HRA practitioners to face questions like:

- How were the data in the HRA obtained and which data sources were used for an assessment (to conduct HRA)?
- What reference values were chosen and why have certain anchors been taken and others left aside?
- Which performance conditions and contextual aspects have been considered and why not others?
- Which event data has been taken as a basis for the assessment and how has the data be exploited regarding a certain HRA?
- How have results from simulator trainings been considered in the HRA?
- Is the unit of analysis in the HRA properly chosen?

These question usually addressed in a review of an HRA could be based on solid grounds quite easily if a common HRA exchange would exist. They show therefore a common set of criteria an exchange can be built upon.

As discussed in Ref. [16], improved event descriptions could serve as a first idea of such an exchange. Minimum requirements for the description of events were identified that could be used already by existing 2nd generation approaches.

Following this idea of helping to find answers to such questions, the factors already discussed as invariant (performance, context and conditions, target behaviors) are much more important than an exchange of HEPs or time reliabilities. HEPs depend anyway on different conditions (different man-machine interface, training and education, etc.) and therefore statistics from other HRAs should take over carefully because the backgrounds for the HRAs are quite different.

3.5. Future challenges of HRA

The fourth invariant in HRA is related to future challenges of HRA. There are a couple of issues pending and waiting to be addressed in HRA.

- Often stressed in this paper was the assessment of errors of commission.
- Related to the errors of commission is the assessment of the impact of organizational changes on safety and the possibilities to incorporate them into PSAs.

Additionally, future technological, economic and organizational changes will challenge HRA more than PSA as a whole:

- New technical specification in the plants: Technical specifications may have an impact on the HRA assessments in PSA. For instance, increasing the power output to meet economic competitiveness with other energy producing systems may lead to changes in the time available for the operators in certain emergencies and therefore this changed specification impacts the human contribution to safety.
- Development of new technology: Errors in design often lead to the problems on the operational level

(unnecessary complex interfaces, complicated procedures, etc.). A tendency, currently observed in all industries, is that design-errors impact the mental workload and reliability of the user to a considerable extend. This effect will also play a role in nuclear safety to some extent, though the technological changes are usually much slower. Such errors in design may probably lead to an extension of HRA into the field of system design.

- Implementation of new technology: New technologies will either substitute completely an old fashioned system or have to be operated in parallel with the conventional system. Both changes may lead to an increased mental effort, either because the operators need to learn the new system or have to switch permanently between old and new technology. The increased mental effort will also increase the potential for errors of commission by the operational staff.
- Staffing changes: Nuclear is a relatively old technology. The average age of staff (as for the entire society) in industrial countries is currently increasing. Overall nuclear will be faced with the issue of loss of knowledge due to retirements [11]. This may have an impact on the basic assumption of HRA: the log-normal distribution. It may have to be changed, because the log-normal distribution assumes highly trained persons for all tasks that are assessed [17].
- Societal acceptance of nuclear: Nuclear is suffering from a lack of public acceptance in many countries. As politics is fairly often related to public opinion and regulators are part of governments, the regulatory influence may change. Governments may change priorities in staffing of regulators and in maintaining the level of knowledge in the regulatory bodies. Some regulators currently extend their business areas to non-nuclear industries in order to assure their future economic existence. Though this has the advantage of taking over experiences from other technologies, a decreased detailed knowledge about nuclear is to be expected in the long term. Therefore the issue of keeping knowledge and organizational issues like safety culture will come up for the regulatory bodies as well as for the scientific support (that is needed for elaborating new safety issues). Beside the utilities, which are currently the main focus of HRA, these parties (regulator, education) may become an item of Human Reliability Assessment themselves in long term.
- These open issues are not yet introduced into the safety assessments but probably will be introduced into PSA because PSA is utilized for decision-making. Overall, these issues put a demand of responsibility on the HRA community. These issues require to increase the robustness of safety related decisions and to support the safety assessment. The concept of risk informed decision making might be a helpful way forward. An international HRA exchange is useful to elaborate on these future safety issues.

4. Conclusions

PSA (and HRA) are processes of thinking about and understanding the safety problems. Concerning the role of human issues, qualitative and quantitative information should be exchanged as this is done in other fields of PSA as well. Consequently the question of exchanging data in the field of human factors is rather more a question of how than a question why.

The existing PSAs should be enhanced by the 'new' HRA methods having in mind that human factors play an important role in plant risk profiles as discussed in this paper. Also other aspects are changing and increasing the importance of HRA in PSA (e.g. operation practice is changed to on-line maintenance, decommissioning, aging of equipment leading to increased importance of maintenance and organizational issues etc.).

There is no way in HRA to substitute the creativity and the flexibility of an HRA expert in order to assure that new safety relevant aspects can be found. Such creativity stems either from evaluation of occurrences, from taking over experiences from other industries or other knowledge gained during the work on the topic. A HRA data exchange may support this activity and may help in managing the experiences already gained somewhere else. Herewith it may release the memory of the HRA expert from 'daily safety issues'.

Hence, an HRA repository for continuos data exchange would be a promising way to go forward. The IRS showed that such an activity leads to real safety improvements just by learning from the experience of plants with a different technology or from the experience gained in other countries.

A similar approach would also help HRA to find the way to improved safety-especially in the field of assessing errors of commission. A data-exchange would allow coming up with a better base for quantification and therefore will lead to improved accuracy in the quantitative assessments.

The big danger is to build an all-encompassing database with too many factors that are never used. Therefore the idea of exchange and feeding potential methods is paramount. As the discussion showed in this paper, a narrative description is the least but not the best one can provide for HRA. Constraints in practicability may also lead to limiting the scope of the database. Basic criteria could be to limit it to those situations where the field data matches the modeling needs.

4.1. The need for HRA data exchange

Without a systematic data exchange regarding HRA issues the data bases for the various existing methods would suffer validity. Without well-founded data it seems to be not possible to prove all the recently developed and of course all the actually used HRA-methods. Consequently the holes in the PSA cannot be filled. The holes discussed in this paper were quite important safety issues like errors of commission, new technology, ageing of the industry and organizational aspects. Safety assessments would remain doubtful regarding the human contribution to risk if the data problem is not solved.

Often the argument of 'conservatism' of HRA methods is brought into discussion with the hope that the pessimistic assessment may cover safety issues rising from human contributions. However, without an appropriate data base this assumption remains unproven. Nuclear industry cannot afford to base its existence on such vague approaches though this has been done in the past years.

Astonishing in this context is that not even the classical 1st generation HRA methods were validated in the past though this could have been done in a much simpler way than for the new 2nd generation HRA methods (e.g. using operational experience with 'classic' statistic methods).

This observation may lead to the conclusion that also the importance of HRA in regulatory risk profiles and the decision-making criteria need to be changed in nuclear safety assessments. However, the HRA community can only achieve this if it realizes a valid and driving contribution to the PSA process.

The question is therefore not whether we need a data exchange but how this can be achieved. Otherwise HRA cannot meet its responsibilities and cannot achieve an assessment of the challenges it is faced with. Though nuclear could afford this under-representation of the treatment of human contributions in the last decades, it may be doubtful whether it can continue like this. PSA and HRA in particular cannot afford to wait until it is proven by a serious accident that one should have worked on the topic.

An HRA data exchange would solve a lot of disputes in the framework of the parties involved in the PSA/HRA process. PSA is dealing with reliability numbers, which sometimes are not leading to new insights into safety but fairly often do provide safety insights. However, the end result of the use of information should not be mixed up with the information that needs to be shared to generate quantitative assessments.

The paper described that data exchange in the HRA field does not mean generating an overall database that contains reliability figures for human actions but rather an exchange that:

- Is not only comparing how to come to a certain number but also how uncertainties are modeled
- Is not looking for a 'baseline' HEP plus the effect of several PSFs modifying this HEP but a sufficiently neutral, relatively theory-free structure for exchanging experiences.
- Is representing the dependencies of conditions and those aspects of cognition that are needed to predict human actions.
- Is containing specific external factors, which can be used to proof effects, observed in event analyses with experimental investigations.
- Is complementing investigations of error mechanisms and conditions in events and experiments.
- Is supporting expert judgement when information or data is missing.

Issues were discussed regarding the enhancement of event reporting and the motivation to build up such a data exchange. The user groups providing information have to be addressed and motivated to join in this activity.

Often events are 'under reported' in the existing event analysis systems [5]. The field data rarely match exactly the modeling needs. Different (new) 'reporting' criteria could be a starting point to start enhancing the quality of event reporting regarding human issues in order to update the PRAs with advanced methods, models, tools and data to improve the evaluation of human issues in PSAs.

The operational experience of the last years is clearly showing that there is no way to circumvent this issue of HRA in safety assessments. Low-power and shut down PSAs require HRA as an essential basis to come up with a good event sequence because most of the plant behavior is driven by the decisions of the operators [18,19]. The development in plant experience is clearly showing worldwide the tendency of increased relevance of human interventions and organizational issues for plant safety. Among the challenging aspects are economy vs. safety, competitive energy markets, decommissioning and aging of the knowledgeable persons in the plants, etc.

These considerations led to the proposal of a new OECD task with the following issues to address:

- Current status of HRA data collection and its usefulness for HRA
- Outlining the evolving consensus model and the associated methodological implications
- Evaluating the sources of risk (operations, maintenance, design, management) to be considered, including future risks
- Evaluating the practices in other fields like air traffic management, railways etc.
- Evaluating whether a common database ('neutral structure') can be efined.
- Evaluating the appropriate level of modeling and the appropriateness of data requirements
- Evaluating a process for information exchange
- Increasing the public relations of HRA
- Evaluating how data exchange can be arranged, maintained and updated

Acknowledgements

The following people participated in the workshop held in Munich in January 2002 on 'Human Reliability Assessment Methods and Data Issues'. This paper would not exist without their comments and contributions during the workshop: Barrientos Montero, Marta (CSN); Bieder, Corinne (Dedale); Blackman, Harold S. (Idaho National Engineering and Environmental Laboratory); Bonaca, Mario (Northeast Utilities); Collier, Steve (OECD Halden Reactor Project); Dang, Vinh (Paul Scherrer Institute); Daniels, Ardela (WANO Paris); De la cal, Cesar (Centrales Nucleares Almaraz-Trillo); D'eer, Anne (Tractebel Energy Engineering); Forester, John (Sandia National Laboratories); Fukuda, Mamoru (Nuclear Power Engineering Corporation); Gertman, David i. (INEEL Lockheed Martin Idaho); Gheorghe, Raducu (Canadian Nuclear Safety Commission); Hollnagel, Erik (University of Linköping); Holmberg, Jan-Erik (VTT Industrial System); Holy, Jaroslav (Nuclear Research Institute rez plc); Huerta Bahena, Alejandro (Nuclear Y Salvaguardias-CNSNS); Julius, Jeff (Scientech, inc.); Kaarstad, Magnhild (OECD Halden Reactor Project); Kaufer, Barry (OECD/NEA); Koeberlein, Klaus (GRS); Lambert, Manuel (IPSN/SECCA); Lanore, Jeanne-Marie (IPSN/DES); Lee, Yong h. (Korea Atomic Energy Research Institute); Murphy, Joseph a. (US Nuclear Regulatory Commission); Okumoto, Masaru (Nuclear Power Engineering Corporation); Park, Jinkyun (Korea Atomic Energy Research Institute); Pesme, Helène (EDF); Popov, Nik (Atomic Energy of Canada limited); Preischl, Wolfang (GRS); Reer, Bernhard (Paul Scherrer Institute); Reny, Daniel a. (Scientiech, Inc.); Shepherd, Charles (Nuclear Installations Inspectorate); Straeter, Oliver (EUROCONTROL); Sung, Key Yong (Korea Institute for Nuclear Safety); Versteeg, Magiel F. (Ministry of Vrom); Vojnovic, Djordje (Slovenian Nuclear Safety Administration); Williams, Jeremy (Nuclear Installations Inspectorate); Wreathall, John (John Wreathall and Company inc.); Yang, Joon-Eon (Korea Atomic Energy Research Institute).

References

[1] Sträter O. GRS-170. Evaluation of Human Reliability on the Basis of Operational Experience. öln/Germany: GRS; 2000. ISBN 3-931995-37-2 at: www.grs.de/grs170.htm.

[2] OECD-NEA, Errors of commission in probabilistic safety assessment. Workshop of the OECD/NEA, Washington: NRC; 2001.

[3] OECD-NEA. Strengthening the link between HRA and data. Workshop of the OECD NEA, Paris: OECD NEA, 2002.

[4] OECD-NEA, Nuclear power plant operating experiences from the IAEA/NEA Incident Reporting System 1996–1999. OECD NEA Publications NEA 02288; 1999. ISBN: 92-64-17671-3, 44 pp.

[5] OECD-NEA, Improving Reporting and Coding of Human and Organizational Factors in Event Reports. OECD/CSNI/R(97)15, Part 1, April 1998, Paris: OECD/NEA; 1998.

[6] IAEA-NEA, IAEA/NEA Incident reporting System (IRS) Reporting guidelines-Feedback from safety related operating experience from Nuclear Power Plants. Vienna: IAEA; 1998.

[7] OECD-NEA, Proceedings of the ICDE Workshop on the qualitative and quantitative use of ICDE Data, held in Stockholm, Sweden on 12–13 June 2001. 2001. NEA/CSNI/R, 8 pp.

[8] OECD-NEA, Errors of Commission in Probabilistic Safety Assessment. NEA/CSNI/R(2000)17, Paris: OECD/NEA; 2000.

[9] IAEA, IRS Study on Incidents Caused by Loss Of Corporate Knowledge And Memory (Phase II-In depth analysis of selected events). Vienna: IAEA; 2001. [IAEA-J4-CS-04/01].

[10] IAEA, IRS study on incidents caused by loss of corporate knowledge and memory (Phase I-Selection of events for in depth analysis). Vienna: IAEA; 2000. [IAEA-J4-CS-10/00].

[11] OECD-NEA, Education and Training-Cause for Concern? Paris: OECD/NEA; 2000.

[12] Sträter O. Group Interaction in High Risk Environments-Communication in NPP. GRS Report No. A-3020, Cologne: GRS; 2002.

[13] Fukuda R, Voggenberger T, Sträter O, Bubb H. Analysis of communication in Nuclear Power Plants. GFA Conference Mai 2003. Munich; 2003.

[14] Reer B, Sträter O, Dang V, Hirschberg S. A Comparative Evaluation of Emerging Methods for Errors of Commission Based on Applications to the Davis-Besse (1985) Event. PSI. Schweiz. Nr., 99-11.; 1999. ISSN 1019-0643.

[15] Sträter O, Zander RM. Approaches to more Realistic Risk Assessment of Shutdown States. Paper for the OECD-Workshop Reliability Data Collection for Living PSA in Budapest, Hungary from 21.4. to 23.4.1998, Paris: OECD NEA; 1998. p. 236ff.

[16] IAEA, Guidelines for describing of Human Factors in the IRS (Human actions and related causal factors and root causes). Vienna: IAEA; 2001. [IAEA-J4-CS-10].

[17] Swain AD, Guttmann HE. Handbook of Human Reliability Analysis with emphasis on nuclear power plant applications. Washington, DC: Sandia National Laboratories; 1983. NUREG/CR-1278.

[18] GRS. SWR-Sicherheitsanalyse, Phase II. Untersuchungen von Ereignissen außerhalb des Leistungsbetriebes. GRS-A-2713. GRS. Köln

[19] Sträter O. The quantification process for human interventions. In: Kafka P, editor. PSA RID-Probabilistic Safety Assessment in Risk Informed Decision making. EURO-Course, 2001. Germany: GRS; 2001. p. 4–9.3.