CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

FOREIGN TRIP REPORT

SUBJECT: High-Level Waste Workshop on Integration of Engineered Barrier Systems in the Safety Case: Design Confirmation and Demonstration
Project Nos. 06002.01.322 and 06002.01.352
AI No. 06002.01.352.619

DATE/PLACE: September 12–15, 2006
Tokyo, Japan

AUTHOR: Sitakanta Mohanty
Center for Nuclear Waste Regulatory Analyses (CNWRA)

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Subject:

CNWRA staff participation in a high-level waste workshop on Integration of Engineered Barrier Systems in the Safety Case: Design Confirmation and Demonstration

Dates of Travel and Countries/Organizations Visited:

September 12–15, 2006, Tokyo, Japan

Author, Title, and Agency Affiliation:

Sitakanta Mohanty, Assistant Director, Engineering and Systems Assessment, CNWRA

Background/Purpose:

The purpose of the trip was to represent the U.S. and the Nuclear Regulatory Commission (NRC) as a delegate, present an invited talk, and participate in working group discussions at the Organization of Economic Cooperation and Development /Nuclear Energy Agency workshop on Integration of Engineered Barrier Systems in the Safety Case: Design Confirmation and Demonstration. This workshop was organized by the Organization of Economic Cooperation and Development /Nuclear Energy Agency in cooperation with the European Commission. Nuclear Waste Management Organization of Japan and Japan Atomic Energy Agency cohosted the workshop.

Abstract–Summary of Pertinent Points/Issues:

The workshop focused on the strategy, approaches, and methods for confirming and demonstrating engineered barrier system design in terms of key constraints and requirements that include long-term safety, engineering practicality, and quality assurance. Experts from the U.S., Belgium, Finland, France, Germany, Japan, the Netherlands, Sweden, Switzerland, U.K., and Taiwan participated in the workshop. The workshop began with eight invited presentations covering a broad range of topics including total-system management approach to engineered barrier system design, methodology for engineered barrier system confirmation and demonstration, current developments in several European national programs on design confirmation and demonstration, examples of engineered barrier system demonstration programs, and lessons learned from performance assessments for engineering design and vice versa. The two presentations from the U.S. were on Yucca Mountain (i) Performance Assessments for Design Reviews by S. Mohanty and T. Ahn (NRC) and (ii) Practical Lessons Learned on the Role of the Engineered Barrier System in a Total System Performance Assessment by A. Van Luik, U.S. Department of Energy (DOE) and D. Sevougian, Sandia National Laboratories.

The workshop also included a technical tour of the Engineering Scale Test and Research Facility and the Quantitative Assessment Radionuclide Migration Experiment Facility at the Japan Atomic Energy Agency's Tokai R&D Center at Tokai-mura, Ibaraki Prefecture. The technical tour provided an understanding of the types and scales of experiments being carried out in Japan in support of their repository site selection and repository design activities.

The desired results were achieved. Participation in the workshop and interactions during breaks strengthened existing networks for sharing experiences with respect to gaining international perspectives on high-level waste repository programs, especially on how to achieve the necessary integration for successful design, construction, testing, modeling, and performance assessment of an engineered barrier system . Overall, the visit provided an opportunity to exchange information on regulatory requirements and experience, engineered barrier system design evolution, use of performance assessments in repository design, and the value of early prototype experiments.

Discussion:

In 2001, the Integration Group for the Safety Case of the Nuclear Energy Agency reassessed the need for a project to develop a greater understanding of how to achieve the necessary integration for successful design, construction, testing, modeling, and performance assessment of engineered barrier systems. The Nuclear Energy Agency intended the project to explore various aspects of engineered barrier system design, construction, and operation processes through a sequence of four workshops. The workshop in Japan was the last of these workshops.

Workshop 1, titled Design Requirements and Constraints, held in Turku, Finland, in 2003, focused on state-of-the-art systematic and fully documented approaches and tools for aiding repository design and optimization. Workshop 2, titled Process Issues, held in Las Vegas, Nevada in 2004, focused on the processes that may influence the design and performance of the engineered barrier system and discussed how processes are determined to be important how they are considered in the design and performance assessment of engineered barrier system; and how they are accounted for in a systematic, defensible, and traceable manner. Workshop 3, titled The Role of Modeling, held in La Coruna, Spain, in 2005, discussed the role of modeling when integrating the engineered barrier system in a safety case, focusing on the necessary integration of successful design, characterization, and performance assessment. Workshop 4, titled Design Confirmation and Demonstration, held in Tokyo, Japan, focused on the strategy, approaches, and methods for confirming and demonstrating EBS design in terms of key constraints and requirements that include long-term safety, engineering practicality, and quality assurance.

Van Luik, DOE and D. Sevougian, Sandia National Laboratories, mentioned that a repository program will manage “what if” scenarios for the engineered barrier system by using industrial analogs although they recognized that such analogs will be limited in scope. Modeling the system assuming it meets design specifications is important but not sufficient to address various “what if” scenarios. They indicated that a combination of industrial analog and modeling studies combined with quality control, even at the material selection stage, should be used to gain confidence on the proposed design. For example, limited but carefully selected and designed sensitivity analyses mimicking potential defects in engineered-system materials, sealing, or emplacement could be used to identify which “what-if” scenarios are more meaningful and the timescale over which these scenarios are meaningful. Likewise, many manufacturing and emplacement issues could be managed using a formalized design-verification process. At a more fundamental level, component materials, even before manufacturing, can have flaws in composition of alloys used. Quality control could assure that no unauthorized substitution of materials not meeting specifications is used.

Mohanty (CNWRA) and Ahn (NRC) concluded that from the regulatory standpoint, any proposed design must meet both long-term performance and operational safety requirements. Performance assessment can guide design reviews by estimating performance (e.g., dose) along with uncertainties in relation to the regulatory threshold and the sensitivity of performance to design parameters. Because large uncertainties may be associated with the long compliance period, the regulations allow the design to evolve as additional information becomes available.

Two one-and-a-half-day-long working group sessions were held during the workshop (i) Working Group Session 1: Decision-Making and the Engineered Barrier System Design Process in the Safety Case and (ii) Working Group Session 2: Confirmation and Demonstration of the Engineered Barrier System in the Context of Confidence Building.

The author participated in Working Group 1. This working group discussed two key topics: (i) Optimization, Balancing Multiple Design Factors and (ii) Iterative Process, Relationship to Performance Assessments and Safety Assessments.

Under topic (i), the group considered the following two questions:

- What factors are considered in engineered barrier system design, and how are they balanced? How are engineering feasibility, practicality, and cost balanced with respect to operational and long-term safety and other requirements?

- How are possible design alternatives selected, justified, and managed?

Under topic (ii), the group considered the following four questions:

- What are the roles of uncertainty and of sensitivity analysis in decisionmaking related to the design and in establishing priorities for confirmation of the performance of the design?

- What are the criteria used to determine an adequate margin of safety, and how is this shown in view of the uncertainties?

- What are the reasons and the procedures used to justify design modifications or even a change to a different design concept? Based on what data? What are the lessons learned from organizations that have already conducted such an iterative process?

- How are the consequences of design changes incorporated back into sensitivity analysis?

Representatives from different countries focused on the repository system at different scales while responding to these questions. For example, the U.S. representatives focused on the repository scale, Japanese representatives on a scale that is equivalent to the DOE total-system management program (e.g., waste production stream, repository site selection, and transportation), and Swedish representatives focused on design of the engineered backfill or buffer. The outcome of the Working Group 1 discussions are presented in summary form in Attachment B.

The outcome of the Working Group 2 discussions are summarized in Attachment C.

The outcome of the Working Group 2 discussions are summarized in Attachment C.

A decision was made to produce a synthesis report for the Engineered Barrier System Project, covering the results of all four workshops. The report will describe the progress regarding engineered barrier system over the course of the project, key messages from all workshops (with specific examples from national programs), and open issues/further challenges identified. The goal is to publish the report by summer 2007.

Attendees endorsed the benefits of the workshops, and there was consensus that maintaining a platform for further collective work under the Nuclear Energy Agency regarding engineered barrier system is valuable. Topics identified for possible future work include: seals and plugs, retrievability considerations in engineered barrier system design, effects of cementitious materials, gas migration, and integrated waste containers.

It is recommended that these types of interactions with foreign organizations continue on various topics related to the performance and design of the potential repository.

Pending Actions/Planned Next Steps for NRC:

None.

Points for Commission Consideration/Items of Interest:

None.

Attachments:

Attachment A:	Business cards of attendees personally contacted
Attachment B:	Working Group 1: Decision-Making and the EBS Design Process in the Safety Case
Attachment C:	Working Group 2: Confirmation and Demonstration of the EBS in the Context of Confidence Building

"On the Margins":

None.

Signatures:

Sitakanta Mohanty

Sitakanta Mohanty, Assistant Director
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10/10/2006
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Concurrence:

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Attachment A

NUMO - Plenary session facilitator

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Gave the opening "statements" at the workshop.

JNES

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Attachment B

Working Group 1: Decision-Making and the EBS Design Process in the Safety Case

EBS-4 Workshop
Tokyo, Japan

14 September 2006

Working Group 1

- Chair: **A. Hooper** (Nirex, UK)
- Rapporteur: **J. Bel** (ONDRAF/NIRAS, Belgium)
- Participants:
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  - BENNETT, David
  - GUNNARSSON, David
  - JOHNSON, Lawrence
  - KAKU, Kenichi
  - KITAYAMA, Kazumi
  - MOHANTY, Sitakanta
  - PAKSY, Andras
  - PELLIGRINI, Delphine
  - SEVOUGIAN, David
  - Shyu, Yuan-horn
  - UEDA, Hiroyushi
  - UMEKI, Hiroyuki
  - VAHANEN, Marjut
  - WOLLRATH, Jürgen

WG1 – Decision-Making & EBS Design in the Safety Case

- **Optimization, Balancing Multiple Design Factors**
  1. What are the main safety functions addressed by the EBS over time? What methods exist for analysis of safety functions?
  2. How does one define and attribute safety functions and their indicators for EBS? How do process understanding, on safety indicators or functions, translate into design requirements?
  3. What factors are considered in EBS design, and how are they balanced? How are engineering feasibility, practicality, and cost balanced with respect to operational and long-term safety and other requirements?
  4. How are possible design alternatives selected, justified and managed?
  5. Is the concept of "best available techniques" applied and if so, how? By what criteria is "best" defined? How could the concept be interpreted over the timeframes for geologic disposal?

3. What factors are considered in EBS design, and how are they balanced? How are engineering feasibility, practicality, and cost balanced with respect to operational and long-term safety and other requirements? (1/2)

Optimisation process:

- Safety basis (pillars) has to be defined before optimisation
- No international, unique prescription for optimisation
- Depends on stage of program and it is an iterative process (in each stage optimisation can be considered but at different levels of detail)
- *Observation*: optimisation is difficult if important uncertainties remain
- A target and methodology is required to guide optimisation
- In some cases, design is modified to accommodate very low probability scenarios
- Ranking of system requirements (ranging from *musts*" to "*shoulds*" to "*nice-to-haves*") is essential to guide an efficient process
- Cost should not be the overriding driving force in the optimisation process

3. What factors are considered in EBS design, and how are they balanced? How are engineering feasibility, practicality, and cost balanced with respect to operational and long-term safety and other requirements? (2/2)

Decisional process:

- How formal does this decisional process has to be ?
  - Decisions should be well-documented
  - Depends on the stage of the program but framework is useful from the beginning
- Integration between engineering (design+construction) and safety analysis has to be achieved at each stage in the process (nature and level of integration depend on stage)
- Frequent review of the design is necessary (continual process)
- Be sure that all requirements have been considered
- Optimisation is a creative process
- While there is a clear need for record of decisions and for a requirement management structure, this does not provide the answer

4. How are possible design alternatives selected, justified and managed?

- Design alternatives exist to address different types of uncertainties (e.g. host rock, site conditions, process uncertainties,….)
- High level requirements should be well defined, justified and ranked; they may change (e.g. dose limits) as the program progresses
- Requirements will evolve as a consequence of changes in design
- Multiple methodologies exist to support the selection process (e.g. multi-criterion analysis) but it will always entail subjective judgement
- Re-evaluate design alternatives after each iteration of safety assessment or selective process analysis
- Prudent to carry alternatives in early stage

WG1 – Decision-Making & EBS Design in the Safety Case

- **Iterative Process, Relationship to Performance Assessments and Safety Assessments**

6. What are the roles of uncertainty and of sensitivity analysis in decision-making, and in establishing priorities for confirmation of performance ?
7. What are the criteria used to determine an adequate margin of safety, and how is this shown in view of the uncertainties?
8. What are the reasons and the procedures used to justify design modifications, or even a change to a different design concept? Based on what data? What are the lessons learnt from organizations that have already conducted such an iterative process?
9. How are the consequences of design changes incorporated back into Safety Assessment?

6. **What are the roles of uncertainty and of sensitivity analysis in decision-making related to the design, and in establishing priorities for confirmation of the performance of the design ?**

- Identify uncertainties in design parameters and environmental conditions, and incorporate these uncertainties through a set of sensitivity analysis
- Rank uncertainties through sensitivity analysis and "uncertainty importance"
- Identification of important parameters and associated uncertainties allows to define priorities for future program for the reduction of uncertainties in the important design parameters
- Sensitivity analysis may help in defining the degree of robustness of the design (***robustness*** is defined as the resilience of a design to the credible range of conditions it will experience)

7. What are the criteria used to determine an adequate margin of safety, and how is this shown in view of the uncertainties? Provocative question! (1/2)

- Margins of safety are not imposed by regulations and standards
- Margin of safety is not necessary if uncertainties are properly accounted for:
  - Uncertainties are typically included in the assessments
  - Assessments often use conservative assumptions
- Margin of safety ultimately has to be evaluated by the regulator
- Margin of safety (numerical indicator) is not the same thing as conservatism (approach)
- What margin of safety is needed to decide no further optimisation is required => depends on strategy of waste management agency regarding the safety case
- Safety relies more on the system robustness than on a safety margin
- No precise prescription of margin of safety seems necessary
- Difference between safety margin of overall system or performance margin of a given component

7. **What are the criteria used to determine an adequate margin of safety, and how is this shown in view of the uncertainties? Provocative question! (2/2)**

Rather than margin of safety, think of strength in depth:

- Reserve functions in the EBS-design
- Design tolerances in the EBS properties and characteristics

8. **What are the reasons and the procedures used to justify design modifications, or even a change to a different design concept? Based on what data? What are the lessons learnt from organizations that have already conducted such an iterative process? (1/3)**

- ***Possible reasons for modification***
  - Results from testing and characterization (lab, small or large scale, in situ)
  - Changes in the boundary conditions (waste inventory)
  - Scenario analysis and modelling
  - (Peer) reviews & comments from regulator or other stakeholders
  - New regulations
  - Change of candidate-sites
  - More general: changes in requirements give rise to modifications

8. **What are the reasons and the procedures used to justify design modifications, or even a change to a different design concept? Based on what data? What are the lessons learnt from organizations that have already conducted such an iterative process? (2/3)**

- ***Procedures used to justify design modifications*****:** need is self-evident
- Based on what data **?**
  - Exchange of information among engineering, geo-science and PA (e.g. effect of inflow on function of bentonite, potential for rock fall on function of canister integrity,…)
  - Important to keep records of the basis of comparison of the designs

8. What are the reasons and the procedures used to justify design modifications, or even a change to a different design concept? Based on what data? What are the lessons learnt from organizations that have already conducted such an iterative process? (3/3)

Lessons learnt from organizations

- Inflexibility/inertia may occur if design is defined in too much detail (science + PA ⇔ design)
- Stakeholder views and changes in regulations, program strategy and site characterization may lead to changes in design
- Level of design details required for PA is less than for engineering
- Importance of FEP's may evolve (PA, science, perception)
- Insufficiently realistic design assumptions & oversimplified design concepts may lead to the need to re-design at a later stage (e.g. early failure, concrete liner, ..)
- Well-defined demonstration tests (of implementation at large scale) at an early stage are important
- Requirements other than LT safety have to be considered in an early stage of the program (this is not the case in some programs)
- Design lay-out as you go in response to real site conditions
- Integration (science, PA, engineering) at an early stage is essential

9. How are the consequences of design changes incorporated back into SA ?

- Obviously by updating models
- Important design changes may modify FEP's screening and may lead to changes in SA models or scenarios
- Consequences should be recorded in direct comparison between designs
- Guidance for new R&D
- Full or focused SA should be performed as appropriate

Attachment C

Working Group 2 Report: Confirmation and Demonstration of the EBS in the Context of Confidence Building

EBS-4 Workshop
Tokyo, Japan

15 September 2006

Working Group 2

- Chair: P. Sellin (SKB, Sweden)
- Rapporteur: A. Van Luik (USDOE, US)
- Participants:
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  - DAVIES, Christophe
  - ISHIGURO, Katsuhiko
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  - TOVERUD, Oivind
  - WEBER, Jan Richard
  - YUI, Mikazu

WG2 – Confirmation and Demonstration of the EBS

- ***Demonstration Experiments***
  - What approaches exist for detailed modelling of EBS in PA and design, based on our understanding of the processes? In particular, how do programmes scale processes in time, and in space, to the level of a disposal system?
    - **Modelling aspects handled in LaCoruna meeting very well.**
    - **Design 'toolbox' is different from PA toolbox.**
    - **Design and PA require models at different levels of detail.**
    - **Experiments at large-scale (demonstrations) can support modeling at larger scales and can appeal to public.**
    - **Modeling spatial scales credible, can verify with mockups where EBS is concerned**
    - **But time-scale is intractable except through addressing future expected effects piecemeal.**
    - **Long term tests (>10 years) can address some aspects, not all.**
    - **Testing of materials not likely to be used can provide analogue-type insights, and allow flexibility if change seems warranted.**

WG2 – Confirmation and Demonstration of the EBS

- **Demonstration Experiments**
  - What has been demonstrated successfully in terms of EBS components, and what remains to be done? (i.e., what can we do well, and what are the practical problem areas associating with fabricating, constructing, and emplacing engineered barriers?)
    - **Merits of large scale experiments are self evident, but none are saving the world, need small-scale test understanding as part of many lines of defense to explain outcomes.**
    - **Iterative multi-scale testing/modelling approach may be warranted.**
    - **Operational safety issues require different information from tests than long-term performance issues.**
    - **Boundary/interface problems may need to be addressed at several scales.**
    - **Small scale tests leading to larger scale tests may be good approach. Sometimes the small scale approach is all that is needed, especially when the effects to be observed are confidently predictable.**
    - **Testing needs are concept-specific: in some cases water pressure at depth may require testing of grouting methods, in other cases grouting can be done by established methods and needs no further work.**
    - **An underground laboratory can be both a demonstration and a test.**

WG2 – Confirmation and Demonstration of the EBS

- **Demonstration Experiments**
  - What further experiments and modelling programs are planned, and with what objectives?
    - Wide range of program-specific responses from participants
      - Range is from manufacturing and emplacement technique tests and demonstrations, to scientific process experiments to improve or substantiate models.
    - Some examples will be cited in the meeting report.
      - Report is not intended to be a comprehensive survey, however.

WG2 – Confirmation and Demonstration of the EBS

- **Demonstration Experiments**
  - What level of practical experience in engineered barrier fabrication, construction, and emplacement have we gained from conducting demonstration experiments and large-scale tests on the EBS or its components?
    - **Manufacturing is tractable, demonstrations have gone well.**
    - **Welding to depths of 19 cm and making buffer-blocks has been demonstrated**
    - **Underground construction is within experience base also (with possible exceptions for high water pressure situations as noted).**
    - **Emplacement has been done on several occasions as demonstrations.**
    - **But there are still problem areas, the largest area is demonstrating processes and approaches at the industrial scale**
    - **Some examples to be discussed in report (not comprehensive).**

WG2 – Confirmation and Demonstration of the EBS

- **Monitoring**
  - What are the role and limitations of monitoring for performance confirmation and demonstration?
    - Demonstration phase (~ 10% of fuel in place) would allow monitoring
    - Monitoring possible during decades of operation (<100 years).
    - After closure, perhaps from 100-1000 years.
    - But what would be meaningful monitoring after closure?
      - Group generally felt that postclosure monitoring would necessarily be very limited
      - Surface monitoring for safeguards purposes may be all that can be done
      - Current technologies are limiting
    - Law may require monitoring, without further specifications

WG2 – Confirmation and Demonstration of the EBS

- **Monitoring**
  - What are likely monitoring parameters?
    - **Temperature, displacement, atmosphere (H).**
    - **Chemical monitoring not likely to be achievable for longer term (with current technology).**
    - **Could we accept requirement to monitor entire system or only some representative cells?**
    - **Meaningfulness questioned:**
      - **What to do with and false positive: sensor deterioration**
      - **How to cope with sensor failure?**
    - **Swiss and US planning separate, accessible drift for monitoring some portion of repository**

WG2 – Confirmation and Demonstration of the EBS

- **Additional Lines of Evidence**
  - What approaches and arguments can be used (in addition to modelling and experiments) to support a demonstration of satisfactory EBS performance in the context of the safety case?
    - **Much discussion of need for sound management and QA approaches to assure confidence**
    - **Best Available Technology requirements have to be interpreted in a practically achievable way, technologies are expected to always change and improve**
    - **Role of local communities in making decisions between viable technological choices discussed**

WG2 – Confirmation and Demonstration of the EBS

- **Additional Lines of Evidence**
  - How can natural and anthropogenic analogues be used to support performance confirmation and confidence-building?
    - **Discussion started with illustration of an iron analogue**
    - **Caution in use of analogues was urged:**
      - **Counter-analogues are possible**
      - **Conditions leading to material preservation need to be understood and comparable with what is expected**
      - **Analogues for engineered systems exist, choice of materials may be made with a view to the availability of analogue information**

WG2 – Confirmation and Demonstration of the EBS

- **Additional Lines of Evidence**
  - What factors have been identified as contributing to confidence in EBS decisions by stakeholders (the public? the local, affected community, the regulators?) Are these factors the same or different from those important, in a technical sense, to demonstrations or confirmations of performance?
    - **This discussion quickly focused on public confidence issues:**
      - **Appearance of EBS materials shown to the public must inspire confidence**
      - **Waste package inspection for acceptance must have some requirements that can be shown to have been met**
      - **Public support may be enhanced by involving representatives from communities in public information efforts and/or in consultations**
      - **Public may respond positively to materials and techniques readily recognized**
        - » **Understandability and Associability concepts apply**