# CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

## TRIP REPORT

**SUBJECT:** International Symposium on Nuclear Fuel Cycle Safety Engineering Research Facility (NUCEF 2005)—AI 20.06002.01.011.021

**DATE/PLACE:** February 9-10, 2005

**AUTHOR:** Wesley C. Patrick

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# CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

## TRIP REPORT

**Subject:** International Symposium on Nuclear Fuel Cycle Safety Engineering Research Facility (NUCEF 2005)

**Dates of Travel and Countries/Organizations Visited**

Travel took place February 7-11, 2005.

Visits were made to the Nuclear Fuel Cycle Safety Engineering Research Facility (NUCEF), the Japan Atomic Energy Research Institute (JAERI), the Japan Nuclear Cycle Development Institute (JNC), and the RICOTTI conference center, all of which are located in the vicinity of Tokai-mura and Mito City, Japan.

**Author, Title, and Agency Affiliation**

Wesley C. Patrick, President, Center for Nuclear Waste Regulatory Analyses (CNWRA), the Federally Funded Research and Development Center sponsored by the U.S. Nuclear Regulatory Commission (NRC).

**Sensitivity**

Not sensitive.

**Background/Purpose**

The purposes of this travel were: to present an invited keynote address titled "The Role of Independent Scientific and Engineering Analyses in the Regulatory Process;" participate in the NUCEF 2005 symposium; and visit certain Japanese laboratories where research in waste disposal, fuel cycle safety, and process engineering is being conducted.

**Abstract: Summary of Pertinent Points/Issues**

The traveller went to Tokai-mura, Ibaraki-ken, Japan February 7-11, 2005 to present a keynote address at the International Symposium NUCEF 2005. The trip was funded under NRC Contract No. NRC-02-02-012, account number 06002.01.011. NUCEF 2005 is an international forum held every 3 years to discuss technical subjects relevant to the nuclear fuel cycle.

NUCEF 2005 featured a series of keynote addresses, special speeches, and technical presentations, as well as poster sessions. Broadly, the topics included criticality safety, radioactive waste disposal, separation processes, and development of safety evaluation methods for fuel-cycle facilities. Highlights of the trip are noted in the following points; details are provided in the section titled Discussion.

The overall purposes of the symposium were to (i) summarize the first decade of research and development and (ii) provide a basis for planning the future research program. In his opening remarks, Z. Yoshida (Deputy Director General of Tokai Research Establishment, JAERI)

highlighted the October 2005 integration of JAERI and JNC into a new institute dedicated to research and development related to nuclear energy. He emphasized that the new organization is striving to (i) enhance the collaboration with industry and university research organizations and (ii) identify more flexible and effective uses of its hot-cell facilities by outside organizations.

K. Sumita (Professor Emeritus Osaka University and consultant) provided an overview of the fuel cycle in Japan, stressing the importance of reprocessing, use of mixed oxide fuels, and deployment of fast breeder technology to meet the long-term energy needs of the nation. Alluding to the 1999 criticality accident at Tokai, he observed that probabilistic safety analysis has not been required for fuel processing and fabrication facilities, as is the case for nuclear power reactors. He opined that deterministic analyses may omit potentially important safety provisions (e.g., evacuation planning) because events either do or do not occur in this analytical framework. Although he did not develop his thinking in this regard, the basic premise is that because deterministic analyses do not permit consideration of likelihoods other than 0 and 1, some potentially important low-probability event sequences (and their associated mitigation and recovery strategies) get omitted (i.e., are tacitly assigned probability of 0).

In the first keynote address, S. Matsumoto (Saitama University) discussed the role and future developments in fuel-cycle safety research. The accidents at the Three Mile Island and Chernobyl nuclear power plants and the accident at the pesticide manufacturing plant at Bhopal, India provided the context for an historical review of the technical and regulatory developments these accidents stimulated. Two principal themes emerged from his remarks. First, he observed that most facilities have very well developed procedures for normal operations and emergency plans for extreme events, but give little attention to the important areas of "bring to safe state" and "return to normal operations." Second, he believes that extensive research is needed in "dynamic simulation" of the development and evolution of, and recovery from, abnormal conditions. Linking these two, he called for changing the current nuclear industry culture from a reactive one with control systems designed for normal and emergency situations to a predictive one that invests significant design effort to understand abnormal occurrences, how they evolve, and how to actively manage them.

A "Special Speech" by L.Koch [former head of nuclear chemistry at the Institute for Transuranium Elements (ITU), Germany, and research advisor to the Central Research Institute of Electric Power Industry (CRIEPI), Japan] described the safety attributes of future fuel cycles. His remarks focused on two primary safety issues: (i) radiotoxicity released to the environment following disposal of the wastes that arise from the fuel cycle; and (ii) proliferation of nuclear weapons. He advocated a pyro-chemical process that is being studied by CRIEPI.

At the invitation of the NUCEF 2005 organizers, I made the second keynote speech of the symposium on the Role of Independent Scientific and Engineering Analyses in the Regulatory Process. This keynote address highlighted the importance of scientific and engineering analyses conducted independently by or for a regulator. It discussed how such analyses enable the regulator to probe the safety analyses of an applicant, and confidently formulate and articulate the technical bases for its regulatory decisions. Selected examples related to a potential repository and interim storage facilities were used to illustrate how scientific and engineering analyses conducted independently on behalf of the NRC are used in the regulatory process.

Parallel technical sessions were held in several areas. The sessions on safety of radioactive waste disposal spanned (i) effects of colloids and microorganisms, (ii) long-term alteration of cementitious engineered barrier materials, (iii) long-term alteration of clay-based engineered barrier materials, (iv) long-term behavior of glass waste forms, and (v) treatment of uncertainties in performance assessment. In the area of fuel-cycle facility safety, topics included (i) databases for criticality safety assessment, (ii) development of transient and static criticality assessment facilities, (iii) development and bench marking of criticality methodologies and related dosimetry, (iv) experiments and analyses related to mixed oxide fuel criticality, (v) the role of burnup credit, (vi) analysis of a potential severe accident during overland transport of fresh nuclear fuel, (vii) safety design for an interim storage facility, and (viii) evaluation of fuel-cycle facility safety under accident conditions. The session on process development was rather limited, comprising three presentations on actinide solution chemistry, pyro-chemical processing of actinides, and advanced aqueous separation technology development.

Following the symposium, the traveller participated in technical tours of the JAERI and JNC research facilities, and took part in related discussions. These facilities are physically extensive, comprehensive across the relevant technical areas, and at the state of the art. Brochures were obtained on the waste disposal and criticality safety research facilities, and can be made available for those interested.

## Discussion

The overall purposes and scope of NUCEF 2005, as well as a summary of the keynote speeches and general addresses are provided in the Abstract. The following discussion focuses on the technical presentations. The reader is referred to the NUCEF 2005 webpage to see the associated abstracts, which were provided for most of the presentations http://typhoon.tokai.jaeri.go.jp/nucef2005/index.html. In addition, NUCEF 2005 intends to post all the presentation graphics on the webpage, once these are released by the organizations that sponsored the research. Authors of presentations and posters have been invited to submit full papers, which will be published in the symposium proceedings.

Parallel technical sessions were held in several areas, as noted in the abstract. Because various sessions ran in parallel, only some could be attended. The following discussion focuses on the sessions attended, but also makes observations based on the traveler reading some of the abstracts and presentations on topics of interest that were addressed in sessions that could not be attended.

K. Ishijima (JAERI) and four of his colleagues summarized the first 10 years of research at NUCEF, and provided a perspective on future research at the facility. Research has been conducted, and is anticipated to continue, in four broad areas: criticality safety, chemical separation processes, radioactive waste disposal, and transuranic (actinide) chemistry. The NUCEF facilities were primarily developed between 1989 and 1995; actual operations and research began in 1995. Collaborators include numerous Japanese universities, research institutes, and private companies; French and European Union organizations; the International Atomic Energy Agency; and the U.S. Department of Energy. Significant accomplishments include developing and using the AGNES computer code to evaluate the 1999 JCO criticality accident, developing criticality data for inclusion in the International Handbook of Evaluated

Criticality Safety Benchmark Experiments, evaluating confinement safety for a large-scale reprocessing facility using a simulation code, demonstrating a four-group partitioning process for high-level liquid waste and a single-cycle process for separation of Np, acquiring chemistry and geochemistry data on long-lived radionuclides, and fabricating an experimental facility to develop data on high-temperature chemistry of actinides. The experimental facility will be used to study separation of minor actinides for subsequent inclusion in fuel. Development of "Rock-like-oxide" (ROX) fuel for burning Pu in light water reactors is also being investigated.

The first session on radioactive waste disposal began with S. Kurosawa (JNC) discussing the effects of colloids and microorganisms on radionuclide migration in fractured rock. Field experiments at the Grimsel facility in Switzerland evaluated *in situ* transport of radionuclides with and without colloids being present. The study suggests that tri- and tetra-valent actinides may form colloids that are more readily transported in shear zones. The experimental results were simulated using the COLFRAC (i.e., colloids in fracture) computer code. Computational and experimental results compared reasonably well, but there was a strong indication of the importance of including in the code sorption kinetics onto colloid.

T. Toraishi (University of Tokyo) examined the influence of naturally occurring organic acids on interactions between radionuclides and colloids in ternary systems. The initial investigation did not consider reversibility of the sorption process or filtration of colloids through the geologic medium.

A. Fujiwara [Radioactive Waste Management Funding and Research Center (RWMC)] completed the session with a discussion of the results of the International Science and Technology Center (ISTC) project. He concluded that an integrated interpretation of colloid effects on sorption has not yet been achieved.

The second session on radioactive waste disposal featured presentations by D. Sugiyama (CRIEPI) on long-term alteration of cementitious materials, T. Tanaka (JAERI) on long-term alteration of bentonite, and Y. Niibori (Tohoku University) on how alkaline groundwater may alter rocks and induce variations in permeability. These studies were conducted at lower temperatures and higher pH values than are anticipated to prevail at the potential repository at Yucca Mountain.

The third session on radioactive waste disposal followed the keynote speech by the traveler. Y. Inagaki (Kyushu University) summarized his work on long-term behavior of glass waste forms. His most important conclusion is that the constant dissolution rate and congruent dissolution modeled in the "H.12 Report" on the feasibility of disposal in Japan were much too conservative. Despite this conclusion, the preponderance of the presentation and discussion highlighted several areas where there is no consensus in the geochemical community, uncertainties remain in the underlying mechanisms, and questions persist about how to incorporate the geochemical understandings into performance assessment and how to validate the resulting glass performance model. Although the specific waste forms and repository conditions differ from those in the U.S. program, this is an area that should be monitored to glean useful information related to high-level waste glass performance.

T. Yamaguchi and his colleagues (JAERI) described their approach to evaluating uncertainties in parameters used in performance assessment. Assuming all parameters are independent, they calculated an "integrated uncertainty" on the order of 400,000 (5.6 orders of magnitude) for the Japanese repository concept. The study did not consider that at least some of the parameters are correlated and that the literature sources were so broadly based that the range of "uncertainty" includes true variability among geologic media and other conditions that are unlikely to all be present at a single repository site.

N. Takeno [Institute for Advanced Industrial and Scientific Technology (AIST)] summarized the results of what appears to be a comprehensive comparison of thermodynamic databases. Because of the importance of these databases, CNWRA/NRC staff should examine this work in more detail.

C. Serres [Radiation Protection and Nuclear Safety Institute (IRSN)] concluded the third session by describing the modeling approach used by IRSN in its independent assessments of the safety of high-level waste disposal in France. There are strong parallels between the IRSN approach and that used by CNWRA/NRC. IRSN uses what they term a "stepwise approach" to assess site conditions, disturbances caused by the repository, contributions of barriers and repository design, and assessment of individual exposures, all taking into consideration uncertainties arising from lack of knowledge and other factors. Like the CNWRA/NRC, IRSN also employs a two-tier modeling approach comprising process-level and total-system (integrated) analyses.

Although the parallel session structure did not permit attending presentations on the safety of fuel-cycle facilities, because of CNWRA/NRC interest in this area, a few observations are provided here based on the traveler reviewing the associated handouts.

- H. Okuno (JAERI) reported on the Nuclear Criticality Safety Handbook Data Collection, Version 2, which is being reviewed by the sponsor before being released. The handbook presents atomic number densities, characteristic parameters for various fuel compositions, subcriticality "judgment graphs" for infinite fuel systems, criticality data for single units, and bench mark calculations of critical experiments. Because of the prevalence of concrete in so many engineering designs, the handbook extends previous data on water-moderated systems to include $SiO_2$-moderated systems.

- C. Pain and his colleagues (Imperial College, UK and Georgia Tech, U.S.) reported on their development of a transient criticality evaluation method, including its implementation in the computer code FETCH. The FETCH code dynamically couples a finite element radiation transport code and a finite element multi-phase fluids code. Results were shown for a number of criticality experiments, as well as for the 1999 JCO criticality accident, a pebble-bed nuclear reactor, and post-closure criticality in a potential geologic repository.

- R. Medioni and colleagues from IRSN summarized the results of the international intercomparison of criticality accident dosimetry systems. In total, some 60

laboratories from 29 countries (including the U.S) participated in either physical or biological dosimetry aspects of the project. The authors reported "fairly good agreement" among the results obtained.

- B. Lance [Belgonucleaire (BN)] described experiments that focused explicitly on criticality safety of a mixed oxide (MOX) fuel fabrication facility. This international program is dubbed KEOPS, for Experimental Determination of K Effective on Various $PuO_2$ Systems. The BN plant has an annual capacity of 35-40 tonnes of heavy metal and uses a process that mixes Pu oxide with either depleted or natural U oxide powder to manufacture the MOX fuel. Criticality management at the BN MOX facility uses a "safe mass" approach to address parts of the process where fissile material is in motion and a "safe geometry" approach to address parts of the process where fissile material is stored (i.e., at rest).

- The BN presentation was followed by a description of the Tools for Sensitivity and Uncertainty Analysis Methodology Implementation (TSUNAMI) by Rearden [Oak Ridge National Laboratory (ORNL)]. TSUNAMI evaluates sensitivity and uncertainty in one- and two-dimensional neutron transport calculations) and was released to the public in the June 2004 version of SCALE5. The ORNL study specifically examined reactor-grade and weapons-grade MOX. It concluded that available experimental data are inadequate and TSUNAMI calculations could improve the design of planned experiments.

- D. Lancaster (NuclearConsultants.com) reported on the status and future of burnup credit in the U.S. His presentation outlined the basic U.S. approach and noted the burnup credit standard (ANS/ANSI-8.27) that is under development. He highlighted that NRC endorses an actinide-only analysis for transportation of pressurized water reactor spent fuel, and that there is no approved analysis approach for boiling water reactor spent fuel. He also noted the DOE plan to use burnup credit at the potential repository at Yucca Mountain. Lancaster presented calculational results for various cases, including borated and unborated pools. He identified three main issues: (i) data are limited for high burnup spent fuel, (ii) available data are from hot (operational) conditions, and (iii) the physical conditions in core and in casks are markedly different (e.g., a large volume of steel in cask configurations that is absent in a reactor core).

- The third session on safety of fuel-cycle facilities ended with a presentation by T. Saegusa on design of an interim storage facility. CRIEPI did verification tests on concrete spent-fuel storage casks, taking into consideration criticality, shielding, containment, and heat dissipation. Investigation of boiling water reactor MOX and pressurized water reactor $UO_2$ spent fuels stored for 20 years apparently showed no deterioration of the spent fuels and comported with calculated results.

- The fourth session on fuel-cycle facility safety comprised three papers. H. Abe and colleagues (JAERI) evaluated the safety of NUCEF itself under accident conditions including criticality and fire. Experimental results and calculations were compared, but

the authors of the paper did not draw clear conclusions; because the traveller does not have technical expertise in this area, conclusions are not offered. S. Tsuchino and Y. Masuhara (JAERI) presented an analytical study of MOX particle behavior during explosion and criticality accidents. MELCOR was used for the criticality study; MOX powder behavior was analyzed using the re-entrainment methodology of Matsusaka. For the explosion scenario, the source term was calculated using the CELVA-1D code. In the final paper, A. Miura (JAERI) reported on using experience from fire and explosion accidents at reprocessing plants and other facilities to evaluate safety of the Japanese reprocessing facility. The work appears to be in its early stages, but will incorporate thermal stability of chemical reagents, process analysis, probabilistic safety assessment techniques, and computer simulation of important processes (e.g., development and propagation of a pressure wave resulting from detonation).

NUCEF 2005 included a poster session. Abstracts for these posters are included at the website provided earlier in this report. Each poster author has been invited to develop a full paper for inclusion in the symposium proceedings volume. Details are not provided here.

Following the symposium, the traveler participated in technical tours of the JAERI and JNC research facilities, as well as related discussions. The principal facilities toured were

- NUCEF, which houses the Static Experiment Critical Facility (STACY), Transient Experiment Critical Facility (TRACY), and Back-end Fuel Cycle Key Elements Research Facility (BECKY)

- Engineering Scale Test and Research Facility (ENTRY), where basic research in geological isolation is conducted

- Quantitative Assessment Radionuclide Migration Experimental Facility (QUALITY), where data are gathered and experiments are conducted on the chemical properties and migration behavior of radionuclides.

These facilities are extensive and at the state of the art. Several papers and posters presented at the conference provide background on the facilities and describe results of experimental activities conducted at them. Brochures were obtained on the waste disposal and criticality safety research facilities, and can be made available for those interested.

**Pending Actions/Planned Next Steps for NRC**

CNWRA and NRC staff should continue to monitor progress in the Japanese program, as part of maintaining awareness of and using results to the extent applicable. In particular, consideration should be given to advances in the following areas.

- Development of radionuclide databases to support geochemical codes to augment and extend the data sources already available.

- Colloid transport investigations and resulting data sets that may be used to calibrate or validate CNWRA/NRC models.

- Waste form dissolution rate and dissolution process (e.g., congruent dissolution).

- Results of the thermodynamic database inter-comparison presented by AIST.

- Criticality and burnup credit methodology development and related benchmarking and verification studies.

**Points for Commission Consideration/Items of Interest**

The following items may be of special interest to the Commission, and should be evaluated by appropriate NRC management to determine whether the items should be forwarded to them.

- Observations about the importance of conducting PRA for fuel cycle facilities.

- Favorable experience of the IRSN, which provides independent technical support to the French regulatory authority, similar to that provided by the CNWRA to the NRC.

- Potential for NRC involvement in criticality studies, as well as possible collaborations that could use the NUCEF hotcell facilities.

**"On the Margins"**

No items were identified to be "on the margins."

**Attachments**
None

**SIGNATURES:**

Wesley C. Patrick
President

2/21/2005
Date

**CONCURRENCE:**

Patrick C. Mackin
Director of Administration

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