OECD-NEA Criticality Working Group - A Status Report and the Burnup Credit Challenge

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INTRODUCTION

The computational methods that are available to criticality safety specialists provide them with the ability to extend their knowledge beyond the data available from experimental data. Given the importance of the computational tool, it is vital that some evidence exists for the validity of the computational methods. One activity that has addressed this important issue is presented in this paper.

At a 1979 meeting of the Fuel Cycle Safety Group, sponsored by the Organization for Economic Co-operation and Development's Nuclear Energy Agency (OECD-NEA), a proposal was submitted for an international intercomparison of criticality calculations relating to the criticality safety of spent light-water-reactor (LWR) fuel element transport casks. The attendees were challenged by the Chairman of the Fuel Cycle Safety Group to prepare a set of problems that would compose the intercomparison test. Based on the problem sets that were presented in response to the request, a Working Group of criticality safety calculation specialists was convened in May 1980.

The following underlying logic for carrying out the work was established; it has proven to be successful in the project, and has been used, essentially unchanged, on all the succeeding efforts of the Working Group. The process was first to identify a set of actual critical experiments that contained the various material and geometric properties present in the spent LWR transport containers. The logic in choosing and applying the experimental data was to be able to establish, in a stepwise fashion, the validity of the method by introducing a new parameter with each new problem. In this way, the effect of the new parameter on the validity of the method can be observed. This procedure was designed to prevent the masking of errors by a combination of negative and positive biases in the results caused by the simultaneous introduction of various parameters, thereby leading to unwarranted confidence in the results. In all cases the primary focus was the adherence to the requirements of the ANS-8.11-1975 Standard, *Validation of Calculational Methods for Nuclear Criticality Safety*. This Standard has subsequently been incorporated into the body of the ANSI/ANS-8.1-1983 Standard, *Nuclear Criticality Safety in Operations With Fissionable Materials Outside Reactors*.

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The final phase of the procedure, after a method was deemed to be validated, was to apply the method in the solution to several hypothetical problems for which the k_{eff} was unknown. As these problems had no known answer, they, in effect, represented a "blind" test that could be used to judge the uniformity of results produced by methods that had been validated against experimental data.

SPENT FUEL TRANSPORT CASKS

Fourteen organizations, representing eleven OECD-NEA countries, participated in this first exercise. Each used the computer method commonly used by their organization. Even though a few participants used identical computer programs and nuclear data, the results of most participants were unique in that either the computer program and/or the nuclear data were not the same as those used by the other members. This variety of methods provided an excellent opportunity to evaluate the hypothesis.

The only major difficulty encountered in extending the use of a method from experimental data to a simulated transport package design was caused by the introduction of parameters that did not exist in the experimental data but did exist in the transport package. The most noticeable of these were the voids in the transport package (this caused difficulty in the diffusion theory methods) and a more complex geometry (that required special care in modeling the transport package with two-dimensional methods). This observation about untested parameter variation has been found to be of concern in all subsequent studies.

The results of the first study have been documented in CSNI Report No. 71, *Standard Problem Exercise on Criticality Codes for Spent LWR Fuel Transport Containers*, May 1982. This document was originally on a restricted distribution. It has now been released for unlimited distribution.

ARRAYS OF PACKAGES OF FISSILE MATERIAL

The success of the first study did not go unnoticed. Immediately upon its completion, a group in the International Atomic Energy Agency (IAEA) that had been studying the regulations on the *transport* of arrays of packages containing fissile material wrote to the OECD-NEA and made a request that the Working Group conduct a study on the *criticality safety* of arrays of packages containing fissile material. OECD-NEA agreed to conduct the study.

Again, as with the first study, a series of experiments were chosen to be the basis for the validation step. Although the first study went very smoothly because of the adequate experimental data base, the second study quickly revealed that some needed experimental data were not available. The first observation was the lack of experiments with large ($>5^3$) arrays of fissile materials (in which each unit is a substantial fraction of a critical mass). The second problem was the lack of experiments involving arrays made up of dissimilar packages containing fissile material. Even though a lack of some needed data was observed, a relatively rich data base allowed the work to proceed. Although we believe that a creditable job was accomplished in addressing the questions raised by the IAEA group, this study clearly showed that additional experimental data would have greatly enhanced the confidence in the results.

This study was documented in CSNI Report No. 78, *Standard Problem Exercise on Criticality Codes for Large Arrays of Packages of Fissile Materials, August 1984*. As with the earlier report No. 71, the restricted distribution requirement has been lifted.

SOLID FISSILE MATERIAL SURROUNDED BY FISSILE SOLUTION

The most recently completed work was, by far, the most ambitious work undertaken by the Working Group. This work represented an effort to establish the validity of computational methods to accurately compute k_{eff} for systems in which fissile material in solid form is surrounded by fissile material in solution. The need for this type of analysis arises in several situations: (1) transport accidents in which the cladding of the fissile material is breached, (2) TMI-2-type reactor accidents, and more commonly, (3) in the dissolution of fuel elements in acid.

From the beginning, the relatively rich data base of experiments that existed for the first two studies was known to be a problem for this new study. Data were available for fissile material in solution and for solid fissile material surrounded by nonfissile solutions. However, for systems with solid fissile material surrounded by fissile solution, which this study addressed, almost no experimental data existed.

The original goal was to proceed as far as possible with the available data in accordance with our original logic for validation. At this point we devised a procedure to attempt to extend the validation through intercomparison of the independent computational methods.

A series of 18 experimentally critical systems were chosen for the first phase. Results of this portion of the study have been documented in NEACRP-L-306, *Standard Problem Exercise on Criticality Codes for Dissolving Fissile Oxides in Acids*, April 1990.

The simulated actual problems that were a part of this study were very challenging, as expected. Two rather complete documents have been produced by two of the French members of the Working Group. These reports contain the results and conclusions of the simulated problem calculations: A. Santamarina and H. J. Smith, *Analysis of the OECD/NEACRP Problem No. 20 on International Criticality Codes for Fuel Pellets in Fissile Solutions*, NEACRP-L-320, December 1990, and H. J. Smith and A. Santamarina, *Analysis of the International Criticality Benchmark No. 19 of a Realistic Fuel Dissolver*, NEACRP-L-325, January 1991.

The current activity of the Working Group focuses on an intercomparison of computational methods used to make criticality calculations in which one seeks to take credit for fuel burnup and/or fission product buildup. This is commonly referred to in the nuclear criticality field as "burnup credit."

In the prior activities of the Criticality Calculations Working Group and, indeed, in most nuclear criticality safety analyses, the commonly made assumption when dealing with spent reactor fuel is that the fuel is fresh, unburned fuel. This assumption has been made for two reasons: (1) the assumption is conservative since the fuel is at its most reactive state when fresh, and (2) very few experimental and computational studies have been performed for spent fuel. The latter, coupled with the uncertainty surrounding the actual isotopic components of a particular fuel element, has led to a reluctance to take burnup credit.

Three major factors have led to a reconsideration of whether to take burnup credit. First, the economics of the industry are such that unnecessary conservatism can no longer be justified. Based on computational studies it is likely that storage and transport capacity can be increased by a factor of 2 in many cases if burnup credit is taken. Second, the desire to increase the burn life of reactor fuel has led to the need to increase the fuel enrichment. With burnup credit it may be possible to continue using current storage and transport facilities for the fuel with higher enrichment. Third, the experimental data available, both on the isotopics of spent fuel and the criticality of reactor cores near or at end of life, will now allow validation of calculations in which burnup credit is taken.

Given this information, the OECD-NEA Criticality Calculations Working Group has undertaken the task of attempting to outline and test a procedure for validation of burnup credit calculations.

As in previous studies, we begin by recognizing that we lack sufficient experimental data to perform the validations as completely as we would like. To this end we will continue to encourage additional critical experiments and to encourage additional analysis to determine the isotopics of fuel with different burnup histories. To compensate for this lack of data it will be important to look for consistency between the various computational methods.

The Working Group has now had its first meeting (see Table 1 for current membership of the Working Group) to discuss results that were submitted for Phase 1 of the study. This first phase has consisted of a simple spent fuel cell. The simplicity of the geometry allows for validation and comparison between computational methods where the variable parameters are burnup, cooling time, and fission products. The identification of the origin of any differences between methods is very important before we can proceed with confidence to the next phase.

The initial results appear to be very good and within the expectations of the Working Group members. Even though these data were encouraging, the members agreed after studying the results to add a Phase 1B set of problems to ensure that we fully covered the validation of simple cells.

During our most recent Working Group meeting, discussions were held to outline the remaining two phases that are expected to be required to complete this study.

Phase 2 will consist of essentially a repetition of the Phase 1 study, except that the analysis will also address the spatial effects, both the axial distribution and an entire PWR fuel assembly. Once this validation has been completed, computations will be made for typical fuel storage and transportation configurations. It is the successful completion of this latter step that will finally provide the confidence that we desire to take burnup credit in our criticality safety analyses.

Finally, the Working Group will conduct a Phase 3 study that will basically repeat Phase 1 and Phase 2 for fuel other that PWRs, for example, BWR, MOX, etc.

SUMMARY

The number of publications produced by this Working Group gives evidence to the very active, results-oriented nature of the Working Group. A major benefit of the work has been the large number of "lessons learned" that have been addressed during the study and that are included in the reports.

The original study in 1980 was viewed as an exercise to judge the value and practicality of an international intercomparison exercise to compare computational methods. The success of the criticality calculation exercises have led to other successful OECD-NEA Working Group

TABLE 1

CURRENT OECD-NEA CRITICALITY CALCULATIONS WORKING GROUP MEMBERSHIP*

Belgium
Thierry Maldague
Belgonucleaire

France
Pierre Albarede
CEN Cadarache

Louis Maubert
CEN Fontenay-aux-Roses

Gilles Poullot
CEN Fontenay-aux-Roses

Alain Santamarina
CEN Cadarache

Germany
Bernhard Gmal
GRS

Hans Heinrich Schweer
Bundesamt fuer Strahlenschutz

Wolf-Juergen Weber
GRS

Italy
Pedro Landeyro
ENEA

F. Siciliano
ENEA

Japan
Makoto Takano
JAERI

Sweden
Dennis Mennerdahl
E. Mennerdahl Systems

United Kingdom
Jim Gulliford
Winfrith Technology Centre

James Stewart
Department of Transport

Peter Rex Thorne
British Nuclear Fuels

United States of America
Michaele C. Brady
Sandia National Laboratory

G. Elliott Whitesides, Chairman
Oak Ridge National Laboratory

OECD/NEA Secretariat
Enrico Sartori
OECD/NEA

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*Finland and Spain have indicated that they will participate in future meetings. Additional representatives from Germany, Japan, Sweden, and the United Kingdom are also expected to participate in future meetings.

computational exercises involving heat transfer and radiation shielding calculation studies.

The enthusiasm for the current burnup credit validation study is evidenced in the record number of participants in the effort. Results were submitted from 23 calculations performed by 17 institutions in 10 countries. It is clear that the burnup credit challenge is an important task and has the potential of having an important economic effect on our industry if the Working Group is successful.

Even though much excitement and interest in this work has been generated, it will require considerable cooperation among the member countries. Much of the experimental data that would be useful to carry out this effort are currently being held as "proprietary" by the various countries. An important factor in the success of this work will be the degree to which the member countries are willing to share their data to further the common good. Through this international cooperation and sharing can come a degree of safety not achievable by any country acting alone.