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NUCLEAR SCIENCE COMMITTEE

SUMMARY RECORD OF THE NSC MEETING ON THE BURNUP CREDIT CRITICALITY BENCHMARK

OAK RIDGE NATIONAL LABORATORY, TENNESSEE, USA

15-17 SEPTEMBER 1993

Summary Record of the NSC Meeting on the Burnup Credit Criticality Benchmark, Oak Ridge, TN,

15-17 September 1993

Introduction

This meeting was held at the Oak Ridge National Laboratory because of the timing of the Nuclear Criticality Conference in Nashville, TN, the following week. Many of the benchmark group members indicated that they would attend the Nashville conference. The location of Oak Ridge was in addition very attractive because technical tours to ORNL and discussion with experts could be arranged.

1. Chairman's introductory remarks

G.E. Whitesides, Chairman of the group, opened the meeting, welcomed the participants and recalled briefly the history of the group's activity. The objective of the group is to validate computational methods through international comparison exercises. Several exercises have already been concluded successfully and are widely used as references. The latest ones in the series concerning burnup credit are quite challenging. The importance attributed by the NEA NSC to these activities was stressed by the NEA Secretariat.

2. General announcements

Plans for the tours and discussions on 17 September were presented :

a) Overview of Martin Marietta Energy Systems
b) Graphite Reactor, the first operating reactor in the world (1943-1963) now a US national monument
c) High Temperature Material Laboratory
d) Aquatic Ecology Laboratory
e) Discussion with ORNL experts

3. Introduction of participants

Nineteen participants attended the meeting (see Annex). The following members sent regrets that they could not participate at this time : L. Maubert (CEA), W. Weber (GRS), P. Landeyro and F. Siciliano (ENEA), T. Maldague (Belgonucléaire), J.M. Conde (CSN), F. Hoejerup (Risoe), M. Yamamoto (Toshiba), P. Grimm (PSI), I. Nojiri (PNC), T.C. Gauld (AECL).

Participants described briefly the responsibilities they have in their laboratories and explained what role and importance burnup credit has in their activities.

Participants represented different activities : computational method development, criticality experiments, licensing and certification of transportation packages, transportation management. An increasing interest in burnup credit criticality studies was noted in Member countries represented at the meeting.

4. Review and approval of the Agenda

The agenda was approved unchanged.

5. Burnup Credit Criticality Benchmark Phase I

Simple PWR spent fuel cell.

a) Final discussion on Phase IA

Makoto Takano presented the latest status of the benchmark, including new and corrected results received after the first draft report had been circulated. Participants were invited to comment and provide their views on some of the discrepancies.

- The overall discrepancies observed are larger than 1%.

- The relative importance of the different components (major and minor actinides, major and minor fission products) were discussed. It was concluded that a major role in burnup credit is played by the actinides. However, because fission products have higher uncertainties their contribution to the overall uncertainty of k is comparable to those of the actinides.

  A sensitivity analysis by nuclide was presented by M. Brady, which shows that burnup credit is sensitive to some of the major actinides and somehow smaller for the fission products. The ranking from highest to lowest importance was as follows : U-238, Pu-239, U-235, Pu-240, Pu-241, Gd-155, Sm-149, Nd-149, Am-241, Sm-151, Cs-133, Tc-99, U-236, Eu-153, Sm-152, Pu-242, Pu-238, Sm-150, Nd-145, Sm-147, U-234, Cs-135.

  The uncertainty due to major actinides is in absolute terms of the same order as the one due to minor actinides. Data uncertainties of both need to be addressed with similar priority.

- The comparisons carried out in this benchmark are not in the k range most important for criticality safety ($k \approx 0.95$).

  . Some of the data sets used have been adjusted for critical systems; this might therefore be one source of discrepancy.

  . Rather large discrepancies are observed in k ranges for above critical (for fresh fuel $k = 1.44 \pm 1.7\%$ (2σ)).

- For criticality safety, accuracy of subcritical systems is more important than for critical systems (deviations of calculated results at k = 1.0 may differ from those at k ≈ 0.95); there is therefore a need to establish whether deviations in critical and subcritical systems are comparable.

- There was a general consensus that a benchmark for k ≈ 0.95 should be defined so that this point can be clarified but should be limited to a small number of cases. (However, it was noted that the most important case is the one for 40 GWd/MTU, for which k ≈ 1.02 at 5 years cooling times which is much closer to the k range of interest.)

- The treatment of resonance overlap and its effect on k was discussed next.

  It was pointed out that a comparison of resonance self shielding group cross sections with continuous Monte Carlo would provide insight into this effect.

  A specific study by JINS (S. Mitake) was presented analysing the source of discrepancies stemming from cross section processing and from the use of different evaluated data libraries. It results that the relative decrease in reactivity is not very sensitive to the method used for the cases considered (27 groups, 137 groups, continuous MC); in this context (comparison SCALE-4 with MGCL-JINS) the difference of 1.1% in k is attributed to differences in the neutron production rates by fissionable nuclides in burned fuels. The larger part of the discrepancies are originated by differences in the evaluated data used.

  Because of this, systematic differences are observed which should be identified as such in the final report.

- Publication of the report :

  The final report, it was concluded, should not only provide the global reactivity loss as a function of burnup and cooling time, but distinguish the contribution due to every relevant component.

  During the discussion as to whether a statement on quality assurance should be added, it was agreed that each participant would provide a statement as to what was done to ensure that valid results were submitted. A sheet should describe which code and what data were used, a retraceable route in the calculations showing the logical progression from the raw data to the working procedures used; in other words enough information should be provided so that someone independent could repeat the calculation.

  The final report will be open, in accordance with the decisions of NSC on benchmark results. The report will be printed by the end of 1993 and distributed in early 1994.

b) <u>Discussions on Phase IB</u>

Phase IB concerns the calculation of the isotopic composition of PWR fuel at different burnups.

M. Brady reported on the progress in compiling the results received. Seventeen contributions were incorporated in a first report comparing results in tabular and graphical form. More contributions are expected to be submitted. The list of participants is enclosed as an Annex.

In summary, calculated concentrations of actinides agree within 10% (except for Pu-238 - underprediction in WIMS because of missing (n,2n) cross sections and α decay of Cm-242). For Neptunium the discrepancies are of the order of 20%. The worst case is Gd-155; also for Sm the discrepancies are large. It was pointed out that Sm-149 predictions may be sensitive to the power history, particularly the power level towards the end of the irradiation. This should not affect this benchmark since the power was the same for all participants. There are large differences in cross sections for Eu and Gd between ENDF/B-V and VI evaluations. Fission product yields and cross sections of the major parent need to be improved for Eu-154 and En-155. (Example : the SCALE burnup library overpredicts Gd-155 concentrations by a factor of 2 due to a low Eu-155 capture phase cross section). Fuel from the Calvert Cliff 1 PWR is being analysed at LANL, PNWL and in Russia through chemical separation and mass spectroscopy in order to improve data on important fission products, in particular Gd, Eu, Sm (lanthanide series) and Rh-103 (Platinum series), the third largest contributor at high burnup. The accuracy on the chemical analysis will be of a few %. The results will be published when the analysis is completed.

In conclusion, there is a 25% uncertainty in predicting fission products in spent fuel. When discrepancies are large, there is a need to look more carefully at the decay chain. Nuclides for which discrepancies are larger than 10% will be added to a special list for closer investigation and analysis.

M. Brady reported also that a NRC report concerning burnup credit is being prepared in 1994 and gives a comprehensive picture of technical work performed to date in the US.

Participants have commented on the results. One source of discrepancy comes from differences in the fission spectrum (Y. Naito). The (n,2n) reaction for obtaining Np has a very sharp rising threshold cross section and therefore also the group structure used covering that threshold and the high energy level of the fission spectrum may be very important.

Cutting off the fission spectrum at 10 MeV as well as not using an actinide dependent fission spectrum may be another source of discrepancy. The self shielding factors for U-236 (capture) is also important. Not using the same atomic masses might be a further source of discrepancy.

Am-243 isotpic results were provided and need to be added to the list of compilation results.

It was decided that the results of Phase IB should form a separate report from IA.

6. Programme of Work for Phase II

Axial burnup effects.

This phase is divided into two parts :

IIA - Axial burnup effects in an infinite array of PWR pins

IIB - Burnup Credit analysis of a typical spent fuel cask

A) Phase IIA

A draft specification proposed by M. Takano, M. Brady and A. Santamarina had been distributed for comments in advance of the meeting. Seventeen members (see Annex) expressed the intention to participate. results for cases 3 and 9 were pre-reviewed in order to facilitate the identification of problems in the specification. The discussion was led by M. Takano. It was agreed to reduce the overall number of cases from 42 to 26 as they are representative of the different parameters in enough detail to enable a drawing of valid conclusions. Axial meshes (regions) were defined including one each for the end plug, and water thickness so that the burnup profile can be represented with sufficient precision. The fission density for each region has been added to the list of results which participants have to provide.

The following schedule was agreed upon :

October 1993	:	distribution of final specification
15 January 1994	:	results should reach M. Takano, JAERI
15 March 1994	:	distribution of draft report Phase IIA
31 March 1994	:	comments on draft back to M. Takano
30 April 1994	:	final draft of Phase IIA for NSC

The question of defining a standard axial burnup distribution was raised. It was agreed that to define a standard axial distribution is important. It helps to define how end effects are calculated which is essential for licensing purposes. Such a standard axial distribution could be based on the large number of measured burnup profiles. This standard profile may differ from the real one and their differences would have to be assessed in practical applications.

Although this is not a major issue in Phase IIA, efforts to define a standard axial burnup distribution were encouraged.

B) Proposals for Phase IIB (Spent fuel flask evaluation)

Two cask models were discussed :

Generic 4-assemblies cask model used by M. Brady (similar to GA-4 design being developed in the US)
TTC5 with seven assemblies

Although Phase IIB addresses a realistic geometry in 3D, the wish was expressed to provide also the equivalent 2D model, for those using deterministic methods.

M. Brady will develop the description.

Different cases will be treated having the following characteristics :

- iron cask
  . enrichment : 4.5 w/o
  . burnup : 30GWd/MTU
  . cooling : 5 years
  . with/without burnup profile (cycle 3 from French PWR)
  . with/without boron in basket
  . with fission products

A tentative schedule for this phase is as follows :

30 November 1993	:	draft specification
15 January 1994	:	comments from members
15 February 1994	:	final specification
39 April 1994	:	results are sent in

This schedule should allow results to be reported to the ICNC'95 conference.

A discussion on further benchmarks that attract international interest followed:

It was concluded that the programme of work should be kept open to other studies and should include different scenarios.

Great interest was shown in burnup effects for BWRs.

Studies in the US (M. Brady) show that there is no advantage in taking into account burnup for BWR fuel shipping casks. A similar conclusion was reached by BNFL.

It is generally believed, however, that burnup credit may be important for storage and disposal of BWR fuel. Burnup credit for BWR fuel is much more complex to calculate than for PWRs (Y. Naito); because of water holes, gadolinia, cross shaped control, etc., pin cell models are not adequate : a full bundle needs to be considered. In addition the Gd concentration needs to be taken into account for burnup credit; an assumption of no Gd would lead to exaggerated safety margins. The radial effects from different fuel enrichments also need to be looked at, although there are indications that the assumption of an average enrichment is conservative, a fact that must be verified and quantified.

Participants agreed that burnup credit for BWR fuel should be placed on the agenda for the next meeting. Proposals for a benchmark should be submitted well in advance of the meeting, and participants should present experience they have acquired in this field.

JAERI volunteered to provide measured BWR burnup profiles to be considered for the study.

A brief discussion was devoted to radial pin burnup effects. Fission products concentrate on the skin of the pin and although the radial profile has little effect on the whole assembly, there is a non negligible effect if single pins are considered. Members agreed that the subject was not worth a special investigation. However, members having experience in this field should prepare a report on the subject for the next meeting.

7. Other business

ICNC'95 Albuquerque, September 1995

This conference is of particular relevance to the group and is co-organised by the OECD/NEA. G.E. Whitesides is the Chairman in charge of international participation. Country representatives should be identified to solicit good quality papers and help in the paper review.

It was agreed that the group's activity should be presented in 2 or 3 papers (Phase IA, Phase IB, Phase IIA and B(?)). Problem coordinators should present the work as parts of it.

A first outline of the paper for Phase IA was presented by M. Takano. The abstracts have to be submitted by 1st October 1994 and the papers by 1st May 1995.

International Cooperation in Criticality Experiments

M. Westfall made a brief presentation on the "Nuclear Criticality Safety Technology Programme of US DoE". One of the subjects addressed is "Physics criteria of quality for benchmark experiments". In addition the US Defense Nucler Safety Board is preparing a report that concerns criticality safety which addresses :

- adequacy of methods and data, status of method, methods enhancement, needs for data, determination of applicability;

- updating of needs for experiments; proposal for experimental programmes have already been made (head of project : R. Malenfant of LANL). The experiments are planned by SNL for different fuel types.

The report will be published in January 1994.

Y. Naito presented the criticality experiments in JAERI, including their Criticality Safety Research and Experimental Facilities. Details were provided in handouts distributed at the meeting. JAERI will offer benchmark data obtained with the experiments described. A list of reports or a catalogue of the benchmarks carried out at JAERI will be offered too.

M. Brady presented the SNL Spent Fuel Safety Experiment (SFSX). The objectives are to produce benchmark quality data for spent PWR fuel for method and data validation. BWR fuel maybe investigated at a later stage. In the US, to obtain regulatory acceptance, criticality calculations involving the use of spent fuel must be validated by comparison with experiments (ANSI/ANS 8.1). This facility provides a means of providing data for validation through an "approach to critical" technique; licensing of the facility is underway. In addition to use for US DoE, it can be used to meet utility and private industry interests and for international applications. More details are provided in the handouts provided at the meeting [4].

M. Poullot presented the short, medium and long term experiments and their objectives that are or will be carried out at the CEA Valduc facility. Three short term experiments concern consolidated clusters in pools (U(4.5 W/o)O_2 rods), mixed arrays (UO_2 and MOX), and a Sm-149 poisoned water basket surrounded by a U(4.5 W/o)O_2 array. In the medium term structural material will be investigated in order to understand better the discrepancies between different data libraries (Cu, Ti, Te, Mo, Zn, $(CH_2)n$, C_2H_5O), simulation of UO_2 dissolution, fission product data validation. The longer term programme includes : fission products in nitric U + Pu solutions, low moderated PuO_2 powder for calculations concerning MOX fuel fabrication, nitric Pu solution with high burnup (30% Pu-240), determination of minimal critical mass for minor actinides (Am-242, Am-243, Cm-245), low enriched (1.1%) uranium solutions.

A. Santamarina & J. Gulliford reported on the DIMPLE and MINERVE experiments, an area in which CEA and AEA cooperate. These experiments are strongly set for data validation and to provide feedback into the JEF evaluated data library. The effects of 12 specific fission products (thermal absorbers) such as Rh-103, Nd-143 and Cs-133 are analysed. Additional information for the MINERVE-MELODIE experiments were provided as handouts [5].

In essence small effects are analysed via perturbation. This effect is complementary to the one presented by M. Brady on SFSX. It appeared clearly that cooperation between the groups would be highly beneficial.

Y. Naito reported that JAERI plans to measure the worth of fission products in the TCA facility.

In general the question was raised whether fission product data mainly developed for reactor applications are of adequate quality for criticality safety calculations. Some consideration should be given to this by the next meeting and experience should be reported.

The Chairman asked participants to provide by the end of November input about the countries' needs and concern about continued support of experiments and computational methods. Together with M. Westfall he will prepare a short statement on the subject for consideration by the NSC.

Proposal for data base of spent fuel assay, nuclide composition data with burnup history

The subject was introduced by Y. Naito, who distributed a paper [7]. In advance of the meeting he had sent a copy of the report JAERI-M-93-061. Y. Naito, M. Kurosawa, T. Kaneko "Data Book of the Isotopic Composition of Spent Fuel in Light Water Reactors" (February 1993). The data is already stored on computer readable form. A full English edition is in preparation.

A LWR Spent Fuel Isotopic Composition Data Base System (SFCOMPCO) has been developed at JAERI with the aim of collecting benchmark data for the evaluation of burnup calculation codes, arranging data so that it can easily be used for evaluations and to facilitate comparison between calculation and experiment.

Data for both PWRs and BWRs are stored away, for 16 actinides and about 12 fission products. The revision of the Japanese Criticality Safety Handbook has been proposed on the basis of SFCOMPCO. The new version will also consider fission products, in addition to actinides. However, only 12 will be considered; the others are rejected on the basis that they are minor absorbers, volatile or semi-volatile and short-lived. It was commended that solubility should also be a criterion for rejection.
The SFCOMPCO data base will be offered by JAERI to the international community.

There was a general consensus that the setting up of SFCOMPCO is an important achievement and that it would be worthwhile and very significant to extend it with other contributions to make it international. JAERI would contribute to its development.

A. Santamarina recommended the Sherwood experiment to be added which concerns PWR assemblies with doped pellets. Other experiments that would be useful are those carried out at the MELUSINE facility in Grenoble, which considered Np and Am.

The Chairman strongly encouraged participants and the countries to share available data. Participants should find out which data sets in their country could be made available for inclusion in SFCOMPCO.

S. Mitake presented a comparison between data from destructive analysis and calculations concerning the isotopic inventory of burnup fuels [6].

Date and Place of Next Meeting

The next meeting will be held from 11-13 July 1994 at OECD Headquarters in Paris.

List of Actions

Phase IA

1.	Members	propose a benchmark for k = 0.95
2.	Secretariat	send Phase IA draft to : Stewart, Poullot, Santamarina
3.	Takano	add S. Mitake paper as Appendix
4.	Members	provide comments and corrections for IA by 15 October
5.	Members	provide distribution list for IA within their country apart from participants
6.	Members	provide statement to Takano about what you did to assure that you have provided valid results
7.	Takano	prepare final report

Phase IB

8.	Members	check results in the tables
9.	M. Brady	request special data from participants for inclusion in the comparison to clarify methods used
10.	M. Brady	prepare draft report for verification by participants

Phase IIA

11.	Parks	prepare new isotopic composition
12.	Takano	prepare revised, final specification
13.	Secretariat	distribute specification (October 1993)
14.	Participants	submit results of Phase IIA via e-mail or 3½" MSDOS to Takano (mid January 1994)
15.	Santamarina	provide the fine flux distribution for cases 2, 6 and 19
16.	Takano	distribute draft report (mid March 1994)
17.	Participants	provide comments and corrections (end March 1994)
18.	Takano/Secretariat	final draft for NSC (end April 1994)
19.	Takano	publication of final report (Summer 1994)
20.	Naito/members	provide proposal for standard axial PWR burnup profile

Phase IIB

21. Brady — prepare cask description and draft problems for comments : end 1993

22. Members — provide comments to Brady : mid January 1994

23. Brady/Secretariat — distribution of final specification (15 February 1994)

24. Members — provide results by end of April 1994

25. Naito — provide measured BWR burnup profile for BWR benchmark

26. Members — report at next meeting on experience on radial pin burnup effects

ICNC'95

27. Members — solicit good papers for ICNC'95

28. Problem coordinators — prepare abstracts and papers for ICNC'95 covering BUC benchmark results

International Cooperation

29. Naito — provide list of reports or catalogue of criticality experiments carried out at JAERI

30. Participants — provide input about countries' needs and concern about continued support for experiments and computational methods to G.E. Whitesides

31. Whitesides — prepare together with Westfall a statement on needs for critical experiments and computational methods

32. Participants — enquire which data sets could be made available for inclusion in the international SFCOMPCO data base; (inform Naito and Secretariat)

List of Papers distributed at the Meeting

1. S. Mitake, O. Sato : A Comparative Study of Neutron Group Constants through the NEA/NSC Burnup Credit Criticality Benchmark, September 1993 (to be added as Appendix to the final report of Phase IA)

2. J.C. Estiot, Maubert, Poullot, A. Santamarina : The Effect of the Axial Burnup Profile, OECD Burnup Credit Criticality Benchmark, Phase IIA, September 1993

3. Y. Naito : Criticality Experiments at JAERI, September 1993

4. M.C. Brady : Spent Fuel Safety Experiment (SFSX) SNL, June 1993

5. A. Santamarina : Burnup Credit Validation of Fission Products Experimental Programme : CERES Phase II
   (List of irradiated fuel samples, concentration of doping fission product, experimental layout MINERVE-MELODIE), September 1993 (in French)

6. S. Mitake, N. Yoshizawa : Evaluation of Isotopic Inventory of Burnup Fuels - Comparison of Destructive Analysis and Calculated Results, September 1993

7. Y. Naito : Proposal for Data Base of Spent Fuel Composition, September 1993

8. JAERI : Nuclear Fuel Cycle Safety Engineering Research Facility (NUCEF) Brochure

9. M.C. Brady : First draft of BUC 1B Benchmark results

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15 September 1993

OECD NUCLEAR ENERGY AGENCY

Membership list

Burnup-credit Criticality Meeting, ORNL 15-17.IX.93

FRANCE

SANTAMARINA, M. Alain
C.E.N. - Cadarache
Bat. 230
CEA/DRN/DER
F-13108 ST. PAUL LEZ DURANCE
CEDEX
Net: smith@frsac11
Tel: +33 42 25 70 46
Fax: +33 42 25 48 49
Tlx: 440678 CEACA

POULLOT, Mr. Gilles
CEA/IPSN/DRS/SEc
CEN Fontenay-aux-Roses
B.P. No. 6
F-92265 FONTENAY-AUX-ROSES
Tel: +33 (1) 46 54 85 66
Fax: +33 (1) 46 57 29 98
Tlx: 270049 SURIN

GERMANY

SCHWEER, Dr. Hans Heinrich
Bundesamt fuer
Strahlenschutz
Albert Schweitzerst. 18
Postfach 100149
D-38226 SALZGITTER 1
Net: schwes10@dbsptb
Tel: +49 (531) 592 7685
Fax: +49 (531) 592 7616

GMAL, Dr. Bernhard
Gesellschaft fuer Anlagen-
und Reaktorsicherheit
Forschungsgelaende
D-85748 GARCHING
Net: gma@dgagrs2a
Tel: +49 (89) 32004 194
Fax: +49 (89) 32004 191
Tlx: 041000 5215110

JAPAN

NAITO, Mr. Yoshitaka
Deputy Director
Department of Fuel Safety
Research
319-11 Tokai-Muri
Naka-Gun, Ibaraki
Tel: +81 292 82 798
Fax: +81 292 82 6199
Tlx: 072000 24596 JTOKAI J

TAKANO, Dr. Makoto
JAERI
Fuel Cycle Safety Eval. Lab.
Tokai Research Establishment
TOKAI-MURA, Naka-gun
Ibaraki-ken 319-11
Net: takano@s4a.tokai.jaeri.go.jp
Tel: +81 (292) 82 5943
Fax: +81 (292) 82 6479
Tlx: 07200 363240

MITAKE, Dr. Susumu
Japan Institute of
Nuclear Safety
Fujita Kankou Toranomon B.7F
3-17-1 TORANOMON
Minato-ku, TOKYO 105
Tel: +81 (3) 5470 5470
Fax: +81 (3) 5470 5454

NOJIRI, Dr. Ichiro
PNC
Tokai Works
Muramatsu Tokai-mura
Naka-gun IBARAKI-KEN 319-11
Tel: +81 (292) 82 1111
Fax: +81 (292) 87 1841
Tlx: J26462 PNRD

SUYAMA, Dr. Kenya
Reactor Physics Laboratory
Dept. of Nuclear Engineering
University of Tohoku
Aoba, Aramaki-ku
SENDAI-SHI 980
Net: kenya@fermi.nucle.tohoku.ac.jp
Tel: +81 (22) 222 1800 X 4679
Fax: +81 (22) 268 1539

SWEDEN

MENNERDAHL, Mr. Dennis
D. Mennerdahl Systems
Pl 457
S-186 41 VALLENTUNA
Net: uems@ems.se
Tel: +46 (8) 5117 8203
Fax: +46 (8) 672 1904

UNITED KINGDOM

THORNE, Dr. Peter Rex
British Nuclear Fuels
Technical Department
R116, Rutherford House
Risley Warrington WA3 6AS
Tel: +44 (925) 833 004
Fax: +44 (925) 833 267
Tlx: 051000 627581

STEWART, Mr. James
Department of Transport
Radioactive Materials
Transport Division S14/19A
2 Marsham Street
LONDON SW1P 3EB
Tel: +44 (71) 276 0503
Fax: +44 (71) 276 5945
Tlx: 22221 DOEMAR

GULLIFORD, Dr. Jim N.
Department Head, Experimental Reactor Physics
AEA Technology
Winfrith Technology Centre
Dorchester, Dorset DT2 8DH
Tel: +44 (305) 20 2795
Fax: +44 (305) 20 2552
Tlx: 41231 atomwh g

UNITED STATES OF AMERICA

BOWMAN, Dr. Steve M.
Building 6011, MS 6370
Oak Ridge National Laboratory
Post Office Box 2008
Oak Ridge, TN 37831-6370
Net: st5@ornl.gov
Tel: +1 (615) 574 5263
Fax: +1 (615) 576 3513
Tlx: 023000 854467

WESTFALL, Dr. R. Mike
Building 6011, MS 6370
Oak Ridge National Laboratory
Post Office Box 2008
Oak Ridge, TN 37831-6370
Tel: +1 (615) 574 5267
Fax: +1 (615) 574 3527
Tlx: 023000 854467

BRADY, Dr. Michaele C.
Sandia National Laboratory
Division 6643
P.O.Box 5800
ALBUQUERQUE, NM 87185
Net: mcbrady@somnet.sandia.gov
Tel: +1 (505) 845 9099
Fax: +1 (505) 844 0244

PARKS, Dr. Cecil V.
Building 6011, MS 6370
Oak Ridge National Laboratory
Post Office Box 2008
Oak Ridge, TN 37831-6370
Net: cvp@ornlstc
Tel: +1 (615) 574 5280
Fax: +1 (615) 576 3513
Tlx: 023000 854467

WHITESIDES, Dr. G. Elliott
Oak Ridge National Laboratory
P.O. Box 2008
OAK RIDGE, TN 37831-6238
Net: GEW@ORNLSTC
Tel: +1 (615) 574 5304
Fax: +1 (615) 574 9646 OR 4532
Tlx: 023000 8105721076 OR 854467

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15 September 1993

OECD NUCLEAR ENERGY AGENCY

Membership list

Participants: Burnup Credit Criticality Benchmark: Phase II A

BELGIUM

MALDAGUE, M. Thierry
Belgonucleaire S.A.
Avenue Ariane 2-4
B-1200 BRUXELLES
Tel: +32 (2) 774 0630
Fax: +32 (2) 774 0614
Tlx: 046000 22187

FRANCE

SANTAMARINA, M. Alain
C.E.N. - Cadarache
Bat. 230
CEA/DRN/DER
F-13108 ST. PAUL LEZ DURANCE
CEDEX
Net: smith@frsac11
Tel: +33 42 25 70 46
Fax: +33 42 25 48 49
Tlx: 440678 CEACA

POULLOT, Mr. Gilles
CEA/IPSN/DRS/SEc
CEN Fontenay-aux-Roses
B.P. No. 6
F-92265 FONTENAY-AUX-ROSES
Tel: +33 (1) 46 54 85 66
Fax: +33 (1) 46 57 29 98
Tlx: 270049 SURIN

GERMANY

SCHWEER, Dr. Hans Heinrich
Bundesamt fuer
Strahlenschutz
Albert Schweitzerst. 18
Postfach 100149
D-38226 SALZGITTER 1
Net: schwes10@dbsptb
Tel: +49 (531) 592 7685
Fax: +49 (531) 592 7616

GMAL, Dr. Bernhard
Gesellschaft fuer Anlagen-
und Reaktorsicherheit
Forschungsgelaende
D-85748 GARCHING
Net: gma@dgagrs2a
Tel: +49 (89) 32004 194
Fax: +49 (89) 32004 191
Tlx: 041000 5215110

ITALY

SICILIANO, Dr. Francesco
ENEA - Centro Comb Trisaia
S.S. 106 Jonica, Km 419+500
I-75025 POLICORO (Matera)
Tel: +39 (835) 974 213
Fax: +39 (835) 974 292
Tlx: 043000 43812585

JAPAN

TAKANO, Dr. Makoto
JAERI
Fuel Cycle Safety Eval. Lab.
Tokai Research Establishment
TOKAI-MURA, Naka-gun
Ibaraki-ken 319-11
Net: takano@s4a.tokai.jaeri.go.jp
Tel: +81 (292) 82 5943
Fax: +81 (292) 82 6479
Tlx: 07200 363240

MITAKE, Dr. Susumu
Japan Institute of
Nuclear Safety
Fujita Kankou Toranomon B.7F
3-17-1 TORANOMON
Minato-ku, TOKYO 105
Tel: +81 (3) 5470 5470
Fax: +81 (3) 5470 5454

ANDO, Mr. Yoshihira
Nuclear Engineering Lab.
Toshiba Corporation
4-1 Ukishima-cho,
Kawasaki-ku
KAWASAKI 210
Net: raa@rcg.nel.rdc.toshiba.co.jp
Tel: +81 (44) 288 8132
Fax: +81 (44) 299 2853

SUYAMA, Dr. Kenya
Reactor Physics Laboratory
Dept. of Nuclear Engineering
University of Tohoku
Aoba, Aramaki-ku
SENDAI-SHI 980
Net: kenya@fermi.nucle.tohoku.ac.jp
Tel: +81 (22) 222 1800 X 4679
Fax: +81 (22) 268 1539

SPAIN

CONDE LOPEZ, M. Jose M.
Head, Core Analysis
CSN
Justo Dorado, 11
28003 MADRID
Net: jmcl@csn.es
Tel: +34 (1) 346 02 53
Fax: +34 (1) 346 05 88

SWEDEN

HELMERSSON, Mr. Sture
ABB-ATOM AB
Reactor Core Engineering
S-72163 VASTERAS
Tel: +46 (21) 107169
Fax: +46 (21) 182737

MENNERDAHL, Mr. Dennis
D. Mennerdahl Systems
Pl 457
S-186 41 VALLENTUNA
Net: uems@ems.se
Tel: +46 (8) 5117 8203
Fax: +46 (8) 672 1904

UNITED KINGDOM

THORNE, Dr. Peter Rex
British Nuclear Fuels
Technical Department
R116, Rutherford House
Risley Warrington WA3 6AS
Tel: +44 (925) 833 004
Fax: +44 (925) 833 267
Tlx: 051000 627581

STEWART, Mr. James
Department of Transport
Radioactive Materials
Transport Division S14/19A
2 Marsham Street
LONDON SW1P 3EB
Tel: +44 (71) 276 0503
Fax: +44 (71) 276 5945
Tlx: 22221 DOEMAR

GULLIFORD, Dr. Jim N.
Department Head, Experimental
Reactor Physics
AEA Technology
Winfrith Technology Centre
Dorchester, Dorset DT2 8DH
Tel: +44 (305) 20 2795
Fax: +44 (305) 20 2552
Tlx: 41231 atomwh g

UNITED STATES OF AMERICA

BOWMAN, Dr. Steve M.
Building 6011, MS 6370
Oak Ridge National Laboratory
Post Office Box 2008
Oak Ridge, TN 37831-6370
Net: st5@ornl.gov
Tel: +1 (615) 574 5263
Fax: +1 (615) 576 3513
Tlx: 023000 854467

PARKS, Dr. Cecil V.
Building 6011, MS 6370
Oak Ridge National Laboratory
Post Office Box 2008
Oak Ridge, TN 37831-6370
Net: cvp@ornlstc
Tel: +1 (615) 574 5280
Fax: +1 (615) 576 3513
Tlx: 023000 854467

BRADY, Dr. Michaele C.
Sandia National Laboratory
Division 6643
P.O.Box 5800
ALBUQUERQUE, NM 87185
Net: mcbrady@somnet.sandia.gov
Tel: +1 (505) 845 9099
Fax: +1 (505) 844 0244