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**NUCLEAR ENERGY AGENCY  
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS**

**Special Expert Group on Fuel Safety Margins**

**SUMMARY RECORD OF THE THIRD MEETING OF THE  
CSNI SPECIAL EXPERT GROUP ON FUEL SAFETY MARGINS**

**Aix-en-Provence, France  
13th May, 2002**

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**SPECIAL EXPERT GROUP ON FUEL SAFETY MARGINS (SEG FSM)**

**SUMMARY RECORD OF THE THIRD SEGFSM MEETING**

**Aix-en-Provence, 13 May, 2002**

**A. HIGHLIGHTS OF THE MEETING**

The **Third Plenary Meeting of the Special Expert Group on Fuel Safety Margins** was held on 13<sup>th</sup> May, 2002 in Aix-en-Provence. The meeting was combined with the second Topical Meeting on RIA Fuel Safety Criteria held on 14<sup>th</sup> and 15<sup>th</sup> May, 2002 at the same place. The plenary meeting reviewed the status of ongoing activities and discussed future activities, in particular:

**General**

1. It adopted the proposed agenda [NEA/SEN/SIN/FUEL(2002)1] without any modifications.
2. It approved the Summary Record of the Second Meeting [NEA/SEN/SIN/FUEL(2001)2] without any modifications.
3. Dr. Wiesenack informed the participants of the presentation which he gave to the CSNI during its December 2001 Meeting, in particular on the achievements of the SEGFSM and ongoing activities, along with the highlights of the Topical Meeting on LOCA Fuel Safety Criteria.
4. Mr. Hrehor briefly informed on the presentation prepared by Dr. Vitanza for the June 2001 CNRA and CSNI meetings as a follow-up to CNRA questions regarding the high burn up fuel.
5. Mr. Hrehor presented the highlights of the last PRG meetings, in particular their impact on SEGFSM activities.

**Review of the ongoing activities**

6. The Group reviewed the draft report on "Ongoing and Planned Fuel Safety Research in NEA Member States" compiled by the external consultant Dr. T. Turnbull. The draft report is at its final stage of comments (comments by June 30). The report will be submitted to the CSNI for approval in December 2002.
7. The Group reviewed the draft report on "An Overview of Fuel Safety Criteria Used in NEA Member States" based on responses from SEGFSM members. The draft report is at its final stage of comments (comments by June 30). The report will be submitted to the CSNI for approval in December 2002.

### **Discussion of future activities**

8. Ms. Andreeva-Andrievskaya presented a proposal to develop "standard" experimental methods to derive LOCA Safety Limits. In line with the conclusions of the LOCA Topical Meeting Ms. Andreeva-Andrievskaya proposed to establish a Task Force and to start working on the collection of information on the existing experimental methods, their comparison and analysis, and to proceed further with a development of the basic points of the a "standard" method(s). The initiation of the activity will depend on the interest of the SEG FSM members.
9. Mr. Belovsky presented a proposal to develop a diffusion model for high-temperature oxidation of Zr-Nb-O tubing. The aim would be to simulate oxidation of Zr-based alloy containing Nb (e.g. E110, M5 or ZIRLO) in transient conditions. The initiation of the activity will depend on the interest of the SEG FSM members.
10. The Group discussed the follow-up to the RIA Topical Meeting - presentation on preliminary LOCA and RIA criteria for high burnup fuel requested by the CNRA for its June meeting. Dr. Wiesenack, along with the Secretariat, will prepare and present a "progress" report for both the CNRA and CSNI committees
11. Mr. Valtonen presented a proposal regarding the licensing codes. He suggested establishing a Working Party together with the GAMA Group with the objectives:
  - to define the status of present licensing codes
  - to identify the high burnup phenomena, which are needed in licensing codes
  - to define the needs to validate the modified codes and
  - to identify the impact of high burnup issues on methodology (best estimate or/and conservative or something else).The initiation of the activity will depend on the interest of the SEG FSM members.
12. The Group came to the consensus that the next topical meeting should revisit the LOCA issue and focus on safety analysis (fuel behaviour models) and LOCA criteria experimental methods.
13. The Group discussed the draft SEG FSM Integrated Plan - containing the SEGFSM mandate and related CSNI/PRG Safety Issues/Topics along with a number of objectives of the SEG FSM's activities derived from them. The draft contains also the proposals mentioned above. The draft document is at its final stage of comments (comments by June 30). The plan will be submitted to the PRG for its endorsement in October 2002.

### **Member countries' activities in the domain of interest for SEGFSM**

14. Dr. Hache presented a paper on Oxidation of Zirconium Alloys at High Pressure Steam (intermediate breaks, transients). Tests in France, possibly in the CINOG facility, will start in 2003 on hydrided Zry-4 and M5 in order to provide missing data.
15. The Group discussed updating information on nuclear safety research facilities at risk (follow-up to the SESAR/FAP report) and status of the fuel safety related experimental data in NEA member countries. Dr. Hache and Dr. Mailliat informed that in their response to the PRG request from September 2001 they had submitted a proposal to the PRG to include the Phebus/FP programme among the facilities listed in the SESAR/FAP report as due to financial difficulties the IRSN is

seriously considering termination of the Phebus FP program. They also proposed adequate modifications of Chapter 3 "Fuel and Reactor Physics" of the SESAR/FAP report.

16. Dr. Mailliat presented the "IRSN Future Programmes: the LOCA Context", in which he described the safety and PHEBUS contexts and outlined the IRSN APRP - Irradié Programme - High Burnup LOCA Tests, which is under preparation.
17. Dr. W. van Doesburg made a presentation on the IAEA working group assessment of differences and common features between PWR and WWER fuel safety criteria. The IAEA report on this comparison will be available in July - August 2002.

**Next Meeting**

18. The Group agreed that the next meeting would be held in March - April 2003 preferably in combination with other fuel related meetings (e.g. Cabri).



## TOPICAL MEETING ON RIA FUEL SAFETY CRITERIA

The third SEGFSM Meeting was followed on 14-15 May, 2002 by **the Second Topical Meeting on RIA Fuel Safety Criteria**. It was organised under the auspices of the CSNI and its Special Expert Group on Fuel Safety Margins in co-operation with IRSN Cadarache. The meeting was chaired by Ms. Joelle Papin (IRSN Cadarache) and Mr. M. José Manuel CONDE LOPEZ (CSN Spain).

In total 50 participants attended. Research and industry organisations from France (IRSN), Finland (VTT), Germany (Framatome-ANP), Hungary (HFKI Budapest), Japan (NUPEC, JAERI), the Russian Federation (Bochvar's Institute, Kurchatov Institute) Sweden (Studsvik AB, Vattenfall Fuel AB), UK (British Energy Ltd.) and the USA (Brookhaven National laboratory, Westinghouse) including the Swiss regulatory body HSK and the Halden reactor project presented 14 papers in all. The papers covered three main areas: "best estimate" core calculations for RIA energy deposition in high burnup fuels, the technical background of current and new RIA fuel safety criteria, and ongoing RIA experimental programmes. A number of open issues were identified, whose resolution is expected from ongoing and planned national and international experimental programmes. The proceedings from the meeting is under preparation.

### Papers presented:

- |   |  |
|---|--|
| T.Nakajima,<br>NUPEC,<br>Japan  | Realistic analysis of RIA in PWR and BWR   |
| D. Diamond,<br>Brookhaven NL,<br>USA  | The Pulse Width During the RIA Transient   |
| V.Malofeev,<br>Kurchatov Institute,<br>Russian federation                                   | Pin-by-Pin Best-Estimate Core Calculation for LWR RIAs   |
| J.C Le Pallec,<br>C. Poinot-Salamon,<br>CEA/Serma ,<br>N. Tricot, IPSN/DES,<br>France       | PWR - Rod Ejection Accident : Impact of<br>High Burn-up and Uncertainties Analysis                               |
| S. Kelppe,<br>R. Kyrki-Rajamäki,<br>S. Rätty, VTT Processes<br>K. Valtonen, STUK<br>Finland | Coupled modelling of fuel behaviour, neutronics, and thermal<br>hydraulics in safety assessments at high burnups |
| J.R. Jones,<br>British Energy Ltd.<br>United Kingdom  | Estimate of the likely plant response to RIA   |

- L. Heins,  
Framatom - ANP,  
Germany                      Representative core calculations of RIA for PWR and BWR
- T.Nakajima,  
NUPEC,  
Japan                              RIA criteria in Japan
- L. Maroti,  
KFKI,  
Hungary                          Review of RIA safety criteria for VVER fuel
- W. van Doesburg,  
HSK,  
Switzerland                      Burnup dependent RIA criteria in Switzerland
- C. Vitanza,  
OECD/NEA                        A Semi-empirical Approach to Burnup Dependent RIA Criteria
- (The "open part" of CABRI seminar )*
- J. Papin et. al.,  
IPSN,  
France                              Main outcomes from the Cabri tests results
- H.Uetsuka  
JAERI,  
Japan                                NSRR RIA tests results and experimental programmes
- K.Kamimura  
NUPEC,  
Japan                                High burnup fuel and cladding characteristics as RIA test initial condition
- L. Egorova, KIAE  
O. Netchaeva,  
Bochvar Inst.,  
Russian Federation              Experimental results of high burnup VVER fuel rods behaviour at the BGR reactor under RIA conditions
- V. Grrigoriev,  
R. Jakobsson,  
D. Schrire,  
Studsvik AB, Sweden,  
R. Kesterson, D. Mitchell,  
Westinghouse, USA,  
H. Pettersson,  
Vattenfall Fuel AB, Sweden.      Impact of Corrosion on Rapid Deformation Capabilities of ZIRLO Cladding.



## **B. DETAILED SUMMARY RECORD**

1. Action items from the third SEG FSM plenary meeting are summarised in Annex I, including a reference to their location in the Summary Record and the deadline agreed.
2. The documents distributed at the meeting are listed in Annex II.
3. A list of participants is provided in Annex III.

## **I. OPENING OF THE MEETING AND ADOPTION OF THE AGENDA**

4. Dr. Wiesenack, the Chairman of the Special Expert Group on Fuel Safety Margins (SEGFSM), opened the meeting and welcomed the participants on behalf of the CSNI. He briefly introduced the SEG FSM programme of work and its methods of work, in particular the plan to organize a series of topical meetings addressing open safety issues related to the fuel safety criteria. The Group decided at its second meeting that the first topical meeting on LOCA fuel safety criteria would be followed by the second topical meeting on RIA fuel safety criteria. Then he proceeded with reviewing the proposed agenda [NEA/SEN/SIN/FUEL(2002)1] which was adopted without modifications.

## **II. APPROVAL OF THE SUMMARY RECORD OF THE SECOND MEETING**

5. The Summary Record of the Second Meeting [NEA/SEN/SIN/FUEL(2001)2] was approved without any modifications.

## **III. STATUS OF THE ACTION ITEMS FROM THE 2<sup>nd</sup> SEG FSM MEETING**

6. Dr. Wiesenack reviewed the action items from the previous meeting. The following remarks were made regarding specific action items:

Action 1: All - done, see para 16

Action 2: Hrehor - an external consultant hired by the Secretariat, see para 16

Action 3: All - done, see para 18

Action 4: W. van Doesburg, Tricot, Valach - done, see para 18

Action 5: Wiesenack, Meyer, van Doesburg - done, see para 9

Action 6: Wiesenack Hrehor - done, see para 7

Action 7: Wiesenack , Hrehor - done, see para 8 .

## **IV. BRIEF SUMMARY OF THE JUNE 2001 AND DECEMBER 2001 CSNI MEETINGS**

7. Dr. Wiesenack informed the participants of the presentation which he gave to the CSNI during its December 2001 Meeting, in particular on the achievements of the SEGFSM and ongoing activities along with highlights of the Topical Meeting on LOCA Fuel Safety Criteria. He pointed out the conclusions from the LOCA meeting and informed that the Group planned for the future, as a follow-up to the LOCA Topical meeting, to initiate compilation of information on existing experimental methods used for study of corrosion behaviour, thermal shock resistance and post quench mechanical properties of fuel claddings

with the aim to identify existing differences, to define a standard test(s) for further experimental studies of LOCA fuel safety criteria and harmonize the presentation and interpretation of experimental results. Then he proposed the CSNI to organize in 2002 the second Topical Meeting on RIA fuel safety criteria, which was endorsed.

8. Dr. Wiesenack also mentioned CSNI requests sent to the all working groups, including the SEG FSM, such as to elaborate WG Integrated Plans, to compile information on data preservation needs, SESAR/FAP report update, etc. In addition, the SEG FSM was asked by the CNRA to respond to questions regarding high burnup fuel, followed by the additional request to present preliminary LOCA and RIA criteria for high burnup fuel. These responses were requested within six months, which did not respect the frequency of SEG FSM meetings (one year), thus they could not always be effectively discussed by the Group. Among other SEG FSM activities, Dr. Wiesenack also mentioned co-sponsoring the IAEA TCM on fuel behaviour under transient and LOCA conditions which was held in Halden from 10 to 14 September, 2001. The activities of the SEG FSM were presented at the IAEA TCM in a paper prepared by him and by the Secretariat.

9. Mr. Hrehor briefly informed on the presentation prepared by Dr. Vitanza for the June 2001 CNRA and CSNI meetings as a follow-up to CNRA questions regarding the high burn up fuel. The presentation was based on outcomes of the LOCA Topical meeting and input from the Chairman and Vice-Chairmen. The presentation, which was very well received by both committees, is available on the special SEG FSM web page.

10. In discussion Dr. Hache suggested to reconsider the interval of the SEG FSM meetings in order to better address various CSNI, CNRA and PRG requests. Mr. Hrehor said that the NEA Secretariat is not against shorter interval between WGs' plenary meetings if there is a substantial deal of work/outcomes to be discussed by the Group.

#### **V. BRIEF REPORT ON THE JUNE AND OCTOBER 2001 MEETINGS OF THE CSNI PROGRAMME REVIEW GROUP (PRG)**

11. Mr. Hrehor briefly presented highlights of the last PRG meetings, in particular their impact on SEGFSM activities. The PRG was established to assist the CSNI and its Bureau in the identification, review and prioritisation of CSNI work. Its basic functions are specified in the PRG Operating Procedures. The PRG has developed a "safety issues/topics list" with the aim to identify and prioritise, at a high level, those safety issues/topics and activities on which the CSNI should be focused. This list will be also used for the review of WG/SEGs new proposals.

12. In December 2000, the CSNI approved a recommendation of the PRG for each of the WG/SEGs to prepare an integrated plan for their activities consistent with their mandate as well as with proposed safety topics. Integrated plans should be top-down documents that start with the group's mandate and the safety topics which are within the group's area of responsibility and identify what ongoing or planned activities of the group will achieve the outcomes described in the mandate and safety topics. A complete integrated plan should identify the activities related to each item in the mandate/safety topic, although first drafts may have sections still to be determined and workshops could identify follow on work.

13. The PRG will annually solicit from the WGs and SEGs up to date information related to facilities and programmes status as an input to SESAR/FAP report update. In this respect the PRG noted that the future of the Phebus reactor is a concern. For further consideration additional information was needed from the IRSN on its intention and schedule. Similar activity will be initiated with respect to data preservation needs. The first step will be to create a list of existing data bases and to assess their status, to identify those

in danger of being lost, and fields which are not covered by the existing databases. A CSNI action will be proposed, if appropriate.

14. In December 2001 the CSNI endorsed the PRG proposal on guidelines for CSNI reports and their approval. The document specifies types of CSNI reports, such as regular reports, technical notes, collective opinions, technical opinion papers, state-of-the-art reports, workshop/seminar proceedings and/or summary and conclusions, their review process, distribution, etc. The guidelines also contains a suggested format and content of executive summaries of the CSNI reports.

15. Mr. Hrehor informed on ongoing discussion within the PRG on the WGs/SEGs role in safety margins. The PRG is considering future CSNI cross-cutting activity addressing safety margin issue. Several WGs/SEGs may be involved in this project including SEGFSM.

## **VI. SEG FSM ACTIVITIES**

### **Review of the ongoing activities**

#### **Draft Report on Ongoing and Planned Fuel Safety Research in NEA Member States**

16. Mr. Hrehor, the Secretary of the SEG FSM, presented the status of work concerning the report on "Ongoing and Planned Fuel Safety Research in NEA Member States". He reminded the participants that the objective of the report was to compile ongoing and planned fuel safety research in NEA Member states with the aim to produce a CSNI report giving an overview on related R&D international and national programmes and projects, along with the identification of current and future needs and priorities. Based on inputs from the SEG FSM members the draft report was compiled by an external consultant (Dr. T. Turnbull) and distributed to the SEG FSM members for comments prior to this meeting. No substantial comments have been received so far. Mr. Hrehor pointed out that the draft report should be finalised by the end of September 2002 and then submitted for PRG review in October 2002 and CSNI approval in December 2002.

17. During the discussion Dr. Hache asked about the intended scope of the report, in particular about molten fuel and severe accident studies - Chapter 10. Dr. Wiesenack explained that the original intention was to focus on "normal" accident fuel conditions without melting. Prof. Asmolov and several other members expressed their wishes to add or to update parts related to their countries. The Group agreed to extend the time for comments and updates by the end of June.

***Action 1:** SEG FSM members to submit comments or updates to the report on fuel related R&D by June 30, 2002*

***Action 2:** Mr. Hrehor to finalise the draft report by September 30, 2002 and submit it for PRG review and CSNI approval.*

#### **Draft report on "An Overview of Fuel Safety Criteria Used in NEA Member States"**

18. Dr. W. van Doesburg informed the participants of the status of work on the report on Overview of Fuel Safety Criteria Used in NEA Member States. The basis for the work was a compilation of responses to a questionnaire survey organized by the CNRA for its June 2000 meeting and responses from SEG FSM members to the revised questionnaire. The drafting group, composed of Dr. van Doesburg, Dr.

Tricot, Dr. Valach and Mr. Hrehor met in March 2002 at HSK Villingen and prepared a draft document in the form of tables which was distributed to the SEG FSM members for comments prior to this meeting. No comments or additional information have been received so far, although some tables remain empty. Similarly to the previous draft report this report should also be finalised by the end of September 2002 and then submitted for PRG review in October 2002 and CSNI approval in December 2002.

19. In the discussion Mr. Hrehor suggested to keep the same schedule as for the R&D report: the comments or additional information should be submitted to the NEA by June 30, 2002. Then the drafting group should prepare a final version by the end of September 2001.

*Action 3: SEG FSM members to submit comments or additional information on fuel safety criteria by June 30, 2002*

*Action 4: The drafting group to prepare a final version of the draft report by September 30, 2002.*

### Discussion of future activities

#### **Follow - up to the LOCA Topical Meeting**

#### **Proposal to develop "standard" experimental methods to derive LOCA Safety Limits**

20. Ms. Andreeva-Andrievskaya presented a paper on LOCA Embrittlement Criteria: Proposal on the Experimental Methods Comparison. She stated that research on the fuel rod claddings, aimed at embrittlement criteria verification, usually comprises the following basic stages: high temperature oxidation, thermal shock tests, mechanical tests (compression, tension, impact, bend), estimation of the hydrogen content, estimation of the oxygen content, metallographic examination (measurement of interaction layers thicknesses and microhardnesses), ceramographic research and structure examination (microrentgenospectral, electron-microscopic). Results of this experimental research depend, to a great extent, on the test parameters and data processing methods. Ms. Andreeva-Andrievskaya then gave a comprehensive overview of different tests conditions and parameters influencing high temperature oxidation and following thermal shock tests and mechanical tests, such as heating mode (direct, indirect), temperature regime (isothermal, non-isothermal), heating/cooling rate, specimen type (one-side oxidation, two-side oxidation), their orientation, etc. All these parameters cause difficulties in comparison with the results between different laboratories. In line with the conclusions of the LOCA Topical meeting Ms. Andreeva-Andrievskaya proposed to establish a task force and to start working on "*standard*" experimental methods to derive LOCA Safety Limits by collection of information on the existing experimental methods, their comparison and analysis, and to proceed further with a development of the basic points of the "standard" method(s). She also proposed as a next step to carry out experiments with simulators of different alloys under the defined "standard" method and conditions with the aim to verify or adjust the embrittlement criteria.

21. Dr. Meyer then presented briefly his position regarding the above-mentioned proposal. He said that in the US they have been trying for almost a year to develop a "standard" experimental method to derive LOCA safety limits for tests in the NRC program at Argonne and the related program at Kurchatov (Prof. Asmolov and Dr. Yegorova). Following earlier work that was thoroughly discussed at the LOCA meeting, they were starting to do ring-compression tests. Then they realized that the ring-compression test results do not give results that can be applied to the burst node, which is exactly where maximum oxidation

is predicted. This is all old information from around 1980, but they have only understood its full significance recently. Consequently, they are now thinking about impact tests (toughness) rather than (or in addition to) ring-compression tests (ductility). They have not yet reached a conclusion on what to do, but they will address it within their ANL research program (with some industry cooperation) this summer. Dr. Meyer then expressed his opinion that it was too early to start talking about a "standard" experimental method although six months ago he would have said that this was a timely subject.

22. An intensive discussion followed the above two presentations. Prof. Asmolov and Dr. Yegorova pointed out that the type of the test depends on the type of criteria to be verified; for example for PCT and ACR the ring compression (ductility) tests are essential although in the "neck" part of a ballooning area these criteria may not be met. Another approach might be to avoid fragmentation of fuel during and after LOCA transient, for which integral tests or impact tests would be the most appropriate. Dr. Mailliat pointed out the difficulties with specimens representing the real reactor conditions. Dr. Hache was of the opinion that the "neck" part of the ballooning area must be taken into account. Dr. Waeckel said that "necking" is not an issue for high burnup fuel and suggested to wait for the results of the next Argonne and Halden LOCA tests. Also, Dr. Mailliat suggested to wait for the next tests. On the contrary, Dr. Vitanza suggested to start working on collecting information regarding the current types of tests methodologies, as a consensus on the definition of the "standard" tests will need a certain time. Dr. Waeckel suggested to focus the next topical meeting on tests methods.

#### **Proposal on development of a diffusion model for high-temperature oxidation of Zr-Nb-O tubing**

23. Mr. Belovsky presented a proposal to develop a diffusion model for high-temperature oxidation of Zr-Nb-O tubing. The aim would be to simulate oxidation of Zr-based alloy containing Nb (e.g. E110, M5 or ZIRLO) in transient conditions. So far there is no tool available allowing to calculate oxygen profile in a Zr-Nb-O cladding after transient. Existing parabolic correlations represent very poor simulation of the reality, especially for pre-oxidized claddings. Diffusion models for Zircaloy are not applicable for Zr-Nb-O (missing Nb and  $\alpha$ - $\beta$  transform). A stand alone model would be applicable for LOCA (& RIA) analyses, in particular for transient oxidation in steam in the range of 600 – 1300 °C (or higher). Among characteristics of the model Mr. Belovský specified:

- solution of 1D diffusion & Stefan equations for oxygen (& niobium) in radial direction
- correction for the O & Nb redistribution between the  $\alpha$  and  $\beta$  phases in the ( $\alpha$ + $\beta$ ) region
- treatment of the  $\alpha$ - $\beta$  transformation due to both the temperature and O & Nb diffusion
- redistribution of the  $\alpha$ - $\beta$  volume fractions
- finite-difference method (Crank-Nicolson), Fortran 77/90, modular structure (SIGAL database)
- concentrations at the layer boundaries taken from the Zr-Nb-O ternary system (not yet completely available).

Expected output parameters would be:

- oxygen weight gain
- oxide thickness(es) & ID & OD
- oxygen & niobium concentration profile
- $\alpha$ -Zr(O) &  $\beta$ -Zr volume fractions.
- the model should be validated against available data from isothermal & transient experiments for E 110, M5, etc.

24. In the discussion Dr. Mailliat pointed out an irregular shape of  $\alpha$  layer and difficulties to model it in a 1D geometry. Dr. Waeckel said that they have done a lot of measurements with M5 alloy and there was no problem with oxygen weight gains. Dr. Hache was of the opinion that such a model might be useful for interpretation of experiments but not for safety analysis; even for Zircaloy such a model is missing due to missing experimental data. Dr. Natchaeva stressed that distribution of hydrogen during

heating and cooling processes are two different processes. Prof. Asmolov expressed doubts about the possibility to validate the model.

### **Follow-up to the RIA Topical Meeting (establishing a TF)/Presentation to CNRA/CSNI**

25. Mr. Hrehor recalled that the SEG FSM was asked by the CNRA in June 2001 to present preliminary LOCA and RIA criteria for high burnup fuel. The CSNI suggested to postpone this presentation after the second topical meeting on RIA fuel safety criteria, which means that the presentation is expected at the June 2002 CNRA meeting. As the RIA meeting will follow this SEGFSM plenary meeting, the Group should now decide how and who will address this request.

26. There was a general sentiment among the participants that the Group cannot present, for the time being, any specific LOCA and RIA fuel safety criteria for high burnup fuel. Such an outcome can only be expected from ongoing research projects. Instead, the Group can make a progress report on its work and outcomes of the topical meetings on LOCA and RIA fuel safety criteria. In the progress report examples of various national approaches might be given, along with an explanation, which are the main issues to be addressed by future research. The discussion was concluded by a decision that the Chairman, along with the Secretariat will prepare and present such a "progress" report.

***Action 5:** The Chairman along with the Secretariat to prepare and present for the June 2002 CNRA meeting a progress report addressing current status of LOCA and RIA fuel safety criteria for high burnup fuel.*

### **Proposal of a benchmark exercise of computer codes modelling high burnup fuel behaviour in accident conditions for licensing purposes**

27. Next, Mr. Valtonen presented a proposal regarding the licensing codes. In the background he said that the recent development of fuel designs and core management (power uprating, longer fuel cycles, burnup extension) have challenged the validity of fuel safety criteria and also the validity of licensing codes. Extrapolation of the existing database is acceptable only to some extent. Mr. Valtonen then gave examples of potential improvements of fuel modelling for three basic types of computer codes such as transient codes, system codes and fuel performance codes. For transient codes the potential improvements might include thermal conductance of the fuel pellet, gap conductance (gap gas pressure and composition), gap width (thermal expansion, elastic deformation, cladding creep, plastic deformation and contact pressure), oxidation and crud deposition, radial power depression, new fuel design related correlations, modelling of burnable poisons, etc. For system codes a subject of improvements might be collapsing of fuel pellet column, radial power depression, ballooning, fuel blockage, transient fission gas release, etc. Finally, in fuel performance codes modelling of most important high burnup effects can be improved along with their thermal-hydraulic models and links between system codes and fuel performance codes. Mr. Valtonen in the conclusion suggested to establish a working party together with GAMA Group. The task of that working party would be:

- to define the status of present licensing codes
- to identify the high burnup phenomena, which are needed in licensing codes
- to define the needs to validate the modified codes and
- to identify the impact of high burnup issues on methodology (best estimate or/and conservative or something else).

28. Mr. Jones and Dr. Mailliat asked additional questions for clarification of the scope of the proposal. They had feelings that the subject was too large and recommended to concentrate on the state-of-

the-art of fuel models in these codes. Dr. Mailliat suggested to wait for new data and check the codes against it.

### **Proposal of the next Topical Meeting**

29. Dr. Wiesenack reminded the participants of the conclusions of the first SEG FSM meeting recommending to organise a series of topical meetings devoted to high priority unresolved fuel safety issues. The first topical meeting was devoted to LOCA criteria. The second topical meeting will focus on RIA related fuel safety criteria, especially with regard to high burnup. The Group also suggested at that time that DNB conservatism and conservatism in 3D core design calculations with respect to shutdown margins could be considered as candidates for future topical meetings. As new potential topics Dr. Wiesenack mentioned safety analysis methods and criteria testing methods.

30. In the discussion, Dr. Mailliat and Dr. Hache suggested repeating the LOCA Topical meeting with a focus on testing methodology and calculations. This suggestion was supported by Dr. van Doesburg, Mr. In de Betou and Dr. Meyer but they were of the opinion that the scope of calculations should be broader and include fuel behaviour models in safety analysis methods/codes. Dr. Wiesenack closed the discussion by summarizing that the Group had come to the consensus that the next topical meeting should revisit the LOCA issue and focus on safety analysis (fuel behaviour models) and also LOCA criteria experimental methods.

**Action 6:** *Dr. Wiesenack and M. Hrehor to prepare a proposal for the CSNI to organize the third SEG FSM topical meeting in 2003 on fuel safety analysis and experimental methods.*

### **SEG FSM Integrated Plan - draft**

31. In the outset Mr. Hrehor recalled the CSNI decision on WGs/SEGs integrated plans (see para 12). All CSNI WGs/SEGs are supposed to start working on their integrated plans and submit them for review to the PRG. In order to assist WGs/SEGs in doing so, the PRG prepared brief guidelines for the preparation of the integrated plans. Mr. Hrehor then introduced the draft document - SEG FSM Integrated Plan - containing the SEGFSM mandate and related CSNI/PRG Safety Issues/Topics, along with a number of objectives of the SEG FSM's activities derived from them, in particular:

#### ***A. Fuel Safety Criteria***

A1. Review Fuel Safety Criteria Currently Used in NEA Member States

A2. Assess the technical basis for current safety criteria and their applicability to high burnup (above 50 MWd/kg) and to new fuel designs and materials

A3. Optimise the use of data for the establishment or revision of fuel safety criteria and make recommendations on the approach to new safety criteria

***B. Fuel Safety Research Programmes***

- B1. Determine needs and priorities for future research programmes in the area of fuel safety behaviour taking into account emerging issues and new fuel types
- B2. Make recommendations on methodologies for experimental work to produce new fuel safety criteria
- B3. Benchmark recommended experimental methodologies among different research laboratories

***C. Fuel Behaviour Codes Development and Validation***

- C1. Review the adequacy of existing codes for simulation of high burnup fuel behaviour in accident predictions
- C2. Co-ordinate further development/improvement of the existing codes for simulation of high burnup fuel behaviour in accident predictions

***D. Analysis of Fuel Behaviour in Accident Conditions***

- D1. Review "best estimate" safety evaluations of postulated design basis accidents to assess existing fuel safety margins, in particular in relation to high burnup fuel
- D2. Revise the CSNI state of the art report No. 129 from 1986 on "PWR Fuel Behaviour in Design Basis Accident Conditions"

***E. Maintaining Fuel Safety Research Capability***

- E1. Collect information on the national fuel safety research facilities and programmes which are at risk to be shutdown and provide input for SESAR/FAP report update.

***F. Maintaining Fuel Safety Experimental Data***

- F1. Collect information on the status of fuel safety related experimental databases in the NEA member countries and provide recommendation to CSNI on appropriate actions to assure their preservation.

***G. Fuel Safety Aspects of Commercially Driven Performance Initiatives***

- G1. Monitor the safety impact of different commercially driven performance initiatives, such as power up-rates, fuel burnup increases, new fuel designs, use of best-estimate codes, etc.
- G2. Provide a forum where safety relevant fuel issues emerging from operating experience and research work can be addressed and resolved in an effective manner.



For each of the above objectives proposed, the document also contained specific actions to achieve them. The actions included the proposals of the new activities as discussed above. The draft integrated plan covered the period 2002 - 2004. In the conclusion Mr. Hrehor invited the group to discuss these proposed actions with the aim to modify/expand or delete them. The document will have to be submitted for the May PRG meeting for a preliminary review and finalised for its October meeting.

32. There was general feeling among the participants that the plan was rather ambitious. Dr. Meyer expressed doubts as to whether he will be able to take part in each proposed action. Mr. Hrehor explained that the original mandate of the Group will expire at the end of this year and the CSNI will consider its prolongation for the next three years based on the proposed programme of the Group. It is in the interest of the Group to propose a plan which addresses all the main objectives of the mandate and which will be technically sound, realistic and feasible. It is also understood that the SEG FSM members will not have to take an active part in each of the proposed and approved actions. The idea is to set up small task forces for them based on the interest of the countries. Among the main activities for the next three years Mr. Hrehor pointed out an update of the CSNI state-of-the-art report on No. 129 from 1986 on "PWR Fuel Behaviour in Design Basis Accident Conditions". The majority of the participants was in favour of the proposal although some members were of the opinion that opened high burn-up issues which are studied in ongoing research programmes will not be fully resolved in the next three years.

33. Dr. Wiesenack closed the discussion of future SEG FSM activities with a suggestion to keep all the above proposals in the integrated plan as the tentative actions. Their initiation will be subject of the interest of the SEG FSM members. He also proposed to give time to SEGFSM members for additional comments by June 30.

*Action 7: SEG FSM members to submit their comments or additional action proposals regarding the draft SEG FSM Integrated plan by June 30, 2002.*

*Action 8: Dr. Wiesenack and Mr. Hrehor to finalise the draft Integrated plan by September 30, 2002 and to submit it for PRG review.*

## **VII. MEMBER COUNTRIES' ACTIVITIES IN THE DOMAIN OF INTEREST FOR SEGFSM**

34. Dr. Hache presented a paper on Oxidation of Zirconium Alloys at High Pressure Steam (intermediate breaks, transients). At the outset he showed the main characteristics (time, pressure, temperatures) of the intermediate breaks (3 inch.) and transients. Referring to available data[1-4] from oxidation tests for Zr 4 and Zr1Nb in high pressure steam he then showed a number of plots, such as Zry - oxide thickness at various temperatures (750- 900 °C) as a function of the square root of time and of steam pressure. As some authors published only Oxide thickness or weight gain, to compare them he used a correlation between weight gain and oxide thickness that he deduced from Pawel's tests. From the data on fresh Zry-4 he draw conclusions, such as:

- effect of partial steam pressure rather than total pressure
- results seem to be related to the compressive stresses-stabilized tetragonal to monoclinic zirconia transformation
- 30-50 bars : enhanced kinetics (> Baker-Just) but limited(no actual safety problem for intermediate breaks with fresh Zry-4)
- 150 bars : more enhanced kinetics (>> Baker-Just) but :
  - relative maximal effect at 750-800°C

- could time at high temperature be sufficient, without reaching 1100°C, during transients (DBA or ATWS)?

For alloys containing Nb:

- data by Vrtilkova at 750°C : pressure effect lower than for Zry-4
- at 850°C and 40 bars : strongly enhanced initial kinetics for E110 alloy (> 17 % ECR - 2 sides, even without wall thinning by ballooning)
- Bochvar Institute published data only at 700°C (Dimitrovgrad IAEA 1995) but recognize that : « the effect of steam pressure ... is marked at higher temperatures ... in contrast to Zry-4 alloy »
- Possible role of Nb on the tetragonal/monoclinic transition
- Lack of data for M5 alloy (and Zirlo ?)/need of tests with M5 (and Zirlo ?)

For high-burnup Zry-4:

- Possible role of H on the tetragonal/monoclinic transition
- Lack of data /need of tests

Dr.Hache concluded his presentation summarizing that for transients parametric plant calculations need to solve the question: could time at high temperature, without reaching 1100°C, be sufficient? For unirradiated Zry-4 there is no actual safety problem for intermediate breaks. Nevertheless for high burnup Zry-4 there is a lack of data and need of tests. For E110 alloy in intermediate breaks a strongly enhanced initial kinetics at 850°C has been observed. Finally for M5 there is again a lack of data and tests are needed. Tests in France, possibly in the CINOG facility, will start in 2003 on hydrided Zry-4 and M5.

#### **References:**

[1] *The oxidation of Zircaloy-4 at 900 and 1100°C in high pressure steam.*

Pawel,-R.E.; Cathcart,-J.V.; Campbell,-J.J. (Oak Ridge National Lab., TN (USA))  
*Journal-of-Nuclear-Materials* (Jun 1979) v. 82(1) p. 129-139.

[2] *An experimental investigation into the oxidation of Zircaloy-4 at elevated pressures in the 750 to 1000 degree C temperature range.*

Bramwell,-I.L.; Worswick,-D.; Parsons,-P.D. (AEA Technology, Warrington (United Kingdom). Risley Lab.); Haste,-T.J. (AEA Technology, Dorset (United Kingdom). Winfrith Technology Centre)  
10. international symposium on zirconium in the nuclear industry. Baltimore, MD (United States) 21-24 Jun 1993.  
ASTM STP 1245 (1994) p. 450-465.

[3] *Oxidizing and hydriding properties of Zr-1Nb cladding material in comparison with zircalloys.*

Vrtilkova,-V.; Molin,-L. (Nuclear Fuel Inst., Zbraslav (Czech Republic)); Valach,-M. (Nuclear Research Inst., Rez plc (Czech Republic))  
*Technical committee meeting on influence of water chemistry on fuel cladding behaviour. Rez (Czech Republic). 4-8 Oct 1993.*  
IAEA-TECDOC--927 (Feb 1997) p. 227-251.

[4] *Pressure effects on high temperature Zircaloy-4 oxidation in steam*

Kwangheon Park, Kwangpyo Kim, Jooho Whang, Kyunghee University, Suwon, South Korea,  
*International topical meeting on Light water reactor fuel performance, Park-City (Utah, USA), 10-13 April 2000*  
CD-ROM proceedings, last poster presentation.

35. Due to shortage of time the paper on "Best Estimate Calculation of LOCA Scenario for VVER 440 with High Burnup Fuel" prepared by Dr. Macek from NRI Rez, Czech Republic was not presented. Dr. Macek will be invited to present it during the third topical meeting.

**Updating information on nuclear safety research facilities at risk (follow-up to the SESAR/FAP report) and status of the fuel safety related experimental data in NEA member countries**

36. Mr. Hrehor recalled that one of the main functions of the PRG is to maintain cognizance of key research facility and programs and to recommend appropriate CSNI actions. To carry out this function the PRG will solicit annually from the WGs and SEGs (see para 13 ) up to date information related to research facilities and programmes, in particular those identified in the recent SESAR/FAP report "*Nuclear Safety Research in OECD Countries: Major Facilities and Programmes at Risk*". The intention is to continue to identify facilities of potential interest for present or future international collaboration, which are threatened by imminent closure, and to make specific recommendations on possible forms of international collaboration and/or joint projects. Similar intention is related to existing data bases from the closed research programmes. Mr. Hrehor then showed Tables/Templates 3.1, 3.2 of the above SESAR/FAP report related to the fuel research and invited participants to comment on the current status of the listed facilities and programmes including related data bases and/or to suggest to include additional facilities/programmes into these tables.

37. Dr. Hache and Dr. Mailliat informed that, in their response to the PRG request from September 2001, they had submitted a proposal to the PRG to include the Phebus/FP programme among the facilities listed in the SESAR/FAP report as, due to financial difficulties, the IRSN is seriously considering termination of the Phebus FP program. In the written comments they proposed adequate modifications of Chapter 3 "Fuel and Reactor Physics" of the report, in particular:

- Para 3.1.3: Phebus should be added in the list of reactors to be maintained
- Table 3.1: Under LOCA issue, it may be worth mentioning that IPSN has a project of program named Phebus LOCA-I in Phebus.
- Template for chapter 3.1: the "No" action needed under the LOCA issue should be re-examined, since there is a potential risk of loss of the operating team and of shutdown of the Phebus reactor if no program is proposed in two to three years, at a time where the resolution of high burn up issues needs further knowledge acquisition.

Mr. Hrehor confirmed that the PRG had received this proposal and had considered it at its October 2001 meeting with the conclusion that additional information from IRSN is needed. Regarding the template for chapter 3.1 Dr. Yang was of the opinion that for RIA studies on higher burnup UO<sub>2</sub> there is sufficient information available now, therefor the word "No" should be replaced with "Yes". There was no indication among participants on any need for action regarding the data preservation. Mr. Hrehor concluded that he will transfer the result of this discussion to the forthcoming PRG meeting in May 30-31.

38. Dr. Mailliat continued with a presentation of the "IRSN Future Programmes: the LOCA Context", in which he described the safety and PHEBUS contexts and outlined the IRSN APRP - Irradié Programme - High Burnup LOCA Tests, which are under preparation. At the outset he characterized the overall situation in the nuclear power domain as follows: constructions and commissioning of nuclear power plants come to very low levels, liberalisation and deregulation induce competition between operators on domestic and international markets, utilities tend to reduce the R&D budgets and enhance the effectiveness of their facilities (increase in reactor power, fuel burn-up, introduction of new types of fuel,

claddings and control rods, fuel cycle lengthening, etc.). Formerly nuclear safety models were designed with wide margins in order to cope with uncertainties both in the data base and the accident phenomenology knowledge and conservative scenarios were taken as a basis for regulation and standard setting. Now, due to continuous demands on plant and core operations there is an increasing tendency of the operators to use best estimate codes and more realistic conditions for accident analyses. These lead to permanent needs to reassess reactor safety studies and provide answer to questions, such as: how much are the margins used by operators, are the criteria always appropriate, are the accident estimates always correct, etc? Answers to these questions should be provided by updating and upgrading of the existing models, through an optimised number of small-scale or semi-integral, out-of-pile or in-pile experiments and a few integral in-pile experiments quantifying the calculation tool uncertainties and margins to criteria. According to this context, the IRSN is preparing two new experimental programmes in the PHEBUS facilities, APRP-Irradié devoted to Loss Of Coolant Accident (LOCA) and PHEBUS 2000 for Severe Accidents.

Dr. Mailliat then listed a number of LOCA pending issues related to fuel relocation in ballooned areas, effects on PCT and ECR due to increase of power and decrease, flow blockage, quenching and also long term cooling, which they plan to address. The proposed in-pile tests should provide the unique way to maintain the heat generation in the fuel fragments whatever the fuel movements are induced by the relocation at burst. Among additional rationale for bundle tests Dr. Mailliat pointed out the following objectives:

- to get correct azimuthal temperature field around the tested fuel rod
- to represent the axial stresses induced by the grids which may restrain rod contraction during quenching
- to represent the effect of the control rod and tube guide on the thermal field and the axial stresses
- to get a realistic value of the flow blockage and the associated heat generation induced by fuel relocation
- to get the realistic complex flow behaviour and quench front progression during reflooding

In the summary Dr. Mailliat said that studies performed in IRSN and elsewhere pointed out that high burnup may induce specific effects under LOCA conditions, especially those related with fuel relocation. One of the important aspect of this IRSN programme is in-Pile experiments involving bundle geometries in the PHEBUS Facility. Uncertainties exist regarding how much these effects might affect the late evolution of the accident transient and the associated safety issues. High Burnup Tests Feasibility Studies will be finalized in summer 2002. The tentative schedule is as follows:

- Basic Design Study Year 2003
- Detailed Design Study Year 2004
- First test envisaged Year 2007.

39. Dr. W. van Doesburg informed on the IAEA working group assessment of differences and common features between PWR and WWER fuel safety criteria. The IAEA has organized three workshops with representatives from Russia, Ukraine and western European countries with the aim to perform a general overview of FSC and their respective basis and to address and explain differences, if any. Two reports, in particular the OECD report NEA/CSNI/R(99)25 „Fuel safety criteria technical review“ and the IAEA report 9316 (Project RER/4/019) „Consultants meetings on fuel safety criteria for VVER reactors“ were taken as a basis for the comparison. For the purpose of this comparison the criteria were divided into the following three categories:

- **Safety criteria: requirements + limits, regulatory approved**  
*Example: safety limit DNB*
- **Operational criteria: limits, mostly regulatory approved, mostly derived from safety criteria**  
*Example: operating limit DNB (PWRs), radial peaking factor (WWERs)*
- **Design criteria: requirements + limits, mostly not regulatory approved; derived from safety/operational criteria**  
*Example: radial peaking factor (PWRs)*

Dr. W. van Doesburg then commented briefly the key outcomes of the comparison for each criterion. The results of this comparison were also provided in distributed handouts. In the overall conclusions he stated that the fuel safety related criteria for both the VVER and western PWR are very similar (if not identical). There are certain differences due to different fuel and/or different reactor type and in some cases, VVER criteria are more conservative (partly due to the Chernobyl accident). The IAEA report on this comparison will be available in July - August 2002.

## **VIII. MISCELLANEOUS**

### **Next Meeting**

40. The Group agreed that the next meeting would be held in March - April 2003 preferably in combination with other fuel related meetings (e.g. Cabri). Also, a combination of the next plenary meeting with the third topical meeting on fuel safety analysis and experimental methods should be considered as an desired option.

## Annex I

## Action Items from the 3rd SEGFSM Meeting

<u>Action</u>	<u>Assignee</u>	<u>Date</u>	<u>Para</u>	<u>Action Item</u>
1.	All	30.6.2002	17	SEG FSM members to submit comments or updates to the report on fuel related R&D
2.	Hrehor	30.9.2002	16	To finalise the draft report on fuel related R&D by September 30, 2002 and submit it for PRG review and CSNI approval.
3.	All	30.6.2002	18	SEG FSM members to submit comments or additional information on fuel safety criteria
4.	Van Doesburg Tricot Valach Hrehor	30.9.2002	19	The drafting group to prepare a final version of the draft report by September 30, 2002.
5.	Wiesenack, Hrehor	18.6.2002	26	The Chairman along with the Secretariat to prepare and present for June 2002 CNRA meeting a progress report addressing current status of LOCA and RIA fuel safety criteria for high burnup fuel.
6.	Wiesenack Hrehor	30.9.2002	30	To prepare a proposal for CSNI to organize the third SEG FSM topical meeting in 2003 on fuel safety analysis and experimental methods.
7.	All	30.6.2002	33	SEG FSM members to submit comments or additional action proposals regarding the draft SEG FSM Integrated plan by June 30, 2002.
8.	Wiesenack Hrehor	30.9.2002	31	Dr. Wiesenack and Mr. Hrehor to finalise the draft Integrated plan by September 30, 2002 and submit it for PRG review.

## Annex II

## List of documents distributed

1. Announcement of the Second Topical Meeting on RIA Fuel Safety Criteria and the Third Plenary Meeting of the CSNI Special Expert Group on Fuel Safety Margins [NEA/SEN/SIN/FUEL(2002)1]
2. The Summary Record of the Second Meeting [NEA/SEN/SIN/FUEL(2001)2]
3. M. Hrehor, NEA Secretariat  
Brief report on the June and October 2001 meetings of the CSNI Programme Review Group (PRG)
4. Draft Report on Ongoing and Planned Fuel Safety Research in NEA Member States (compiled by T. Turnbull)
5. Draft report on "An Overview of Fuel Safety Criteria Used in NEA Member States" (compiled by Dr. W. van Doesbug et.al.)
6. L.N. Andreeva-Andrievskaya, N.B. Sokolov, VNIINM, Russian federation  
LOCA Embrittlement Criteria: Proposal on the Experimental Methods Comparison.
7. R. Meyer, US NRC
8. L. Belovsky  
A proposal to develop a diffusion model for high-temperature oxidation of Zr-Nb-O tubing.
9. K Valtonen, STUK, Finland  
Proposal of a benchmark exercise of computer codes modelling high burnup fuel behaviour in accident conditions for licensing purposes
10. M. Hrehor  
SEG FSM Integrated Plan - draft
11. G. Hache, IRSN, France  
Oxidation of Zirconium Alloys at High Pressure Steam (intermediate breaks, transients).
12. G. Hache, A. Mailliat, IRSN, France  
Comments to SESAR/FAP Report - on Phebus reactor
13. A. Mailliat, IRSN, France  
IRSN Future Programmes: the LOCA Context





## Annex III

List of Participants  
 Third Plenary Meeting of the CSNI Special Expert Group on Fuel Safety Margins  
 Aix-en-Provence, 13 May, 2002

**BELGIUM**

Dr. Nadine HOLLASKY  
 AVN Association Vinçotte Nuclear  
 Rue Walcourt, 148  
 B-1070 Brussels

Tel.: +32 0 2 5280244  
 Fax: 32 0 2 5280102  
 Eml.: nh@avn.be

Dr. Marc VERWERFT  
 SCK/CEN  
 Reactor Materials Research  
 200 Boeretang  
 B-2400 MOL

Tel.: +32 14 33 30 48  
 Fax: +32 14 32 12 16  
 Eml.:mverwerf@sckcen.be

Mr. Albert CHARLIER  
 Tractebel Energy Engineering  
 Avenue Ariane 7  
 B-1200 BRUXELLES

Tel: +32 2 773 98 67  
 Fax: +32 2 773 89 00  
 Eml: Albert.Charlier@tractebel.com

**CZECH REPUBLIC**

Dr. Mojmir VALACH  
 Nuclear Research Institute  
 Dept. of Reactor Technology  
 25068 - REZ U PRAHY

Tel.: +420 2 6617 2100  
 Fax: +420 2 6617 2100  
 Eml.: valach@ujv.cz

Mr. Ladislav BELOVSKY  
 ALIAS CZ s.r.o.  
 Bachova 1586/16  
 149 00 Praha-415

Tel. (+420) 2 272 921 678  
 Fax (+420) 2 57 21 28 66  
 E-mail: belovsky@telecom.cz

Dr. Jiri MACEK  
 Head  
 Thermal-Hydraulic Analyses Department  
 Nuclear Research Institute Rez plc  
 250 68 REZ

Tel: +420 2 20940 954  
 Fax: +420 2 20940 954  
 Eml: mac@ujv.cz

Dr. Alexander MIASNIKOV  
 State Office for Nuclear Safety  
 Senovazne namesti 9  
 110 00 Prague 1

Tel.:+420 2 216 24 732  
 Fax: +420 2 216 24 202  
 Eml.:alexander.miasnikov@sujb.cz

Mr. Svatobor STECH  
Dukovany Nuclear power Plant  
675 50 Dukovany

Tel: +420 618 81 3690  
Fax: +420618 866 495  
Eml: stechs1.edu@mail.cez.cz

**FINLAND**

Mr. Seppo KELPPE  
VTT Energy  
P.O. Box 1604  
FIN-02044 VTT

Tel.: +358 9 456 5026  
Fax: +358 9 456 5000  
Eml.: seppo.kelpe@vtt.fi

Mr. Keijo VALTONEN  
Finnish Centre for Radiation  
and Nuclear Safety (STUK)  
P.O. Box 14  
SF-00881 HELSINKI

Tel.: +358 (9) 759 331  
Fax: +358 (9) 759 88382  
Eml.: keijo.valtonen@stuk.fi

**FRANCE**

Mr. Georges HACHE  
IRSN/DRS  
Bat 250  
CEA/Cadarache  
13108 ST PAUL LEZ DURANCE Cdx

Tel.: +33 4 42 25 20 55  
Fax: +33 4 42 25 76 79  
Eml.: georges.hache@irsn.fr

Mme. Joelle PAPIN  
IRSN/DRS/SEMAR  
CEA/CEN/CADARACHE  
13108 Saint Paul lez Durance  
Cedex

Tel.: +33 + 33 4 42 25 34 63  
Fax: +33 + 33 4 42 25 61 43  
Eml.: joelle.papin@irsn.fr

Mr. Nicolas TRICOT  
IRSN/DES  
CEN FAR  
BP 17  
92262 FONTENAY AUX ROSES  
CEDEX

Tel.: +33 (0)1 46 54 90 34  
Fax: +33 (0)1 46 54 95 99  
Eml.: nicolas.tricot@irsn.fr

Mr. Patrice DESCHAMPS  
IRSN/DES  
CEN FAR  
BP 17  
92262 FONTENAY AUX ROSES  
CEDEX

Tel.:  
Fax:  
Eml.:patrice.deschamps@irsn.fr

Dr. Nicolas WAECKEL  
EDF/SEPTEN  
12-14 Avenue Dutrievoz  
69628 Villeurbanne Cedex F

Tel : 04 72 82 72 44  
Fax : 04 72 82 77 11  
Eml : nicolas.waeckel@edf.fr

Dr. Alain MAILLIAT  
Head of Project  
IRSN/DRS/DIR - Bat 250  
CEA - CEN Cadarache  
F-13108 St Paul-lez Durance Cedex

Tel : +33 4 42 25 36 37  
Fax: +33 4 42 25 29 29  
Eml.: alain.mailliat@irsn.fr

Mr. C. GETREY  
IRSN/DES  
CEN/FAR  
92262 Fontenay-aux-Roses

Tel.: +33 1 46 54 85 16  
Fax: +33 1 46 54 95 99  
Eml.: christophe.getrey@irsn.fr

Mr. Jean-Charles LE PALLEC  
CEA Saclay bat. 470  
DM2S/SERMA/LCA  
91191 Gif-Sur-Yvette Cedex

Tel. : +33 1 69 08 26 26  
Fax : +33 1 69 08 23 81  
Eml: lepallec@soleil.serma.cea.fr

Mr. A. FRICHET  
Framatome ANP  
10 rue Juliette Récamier  
69456 LYON Cedex 06

Tel. : +33 4 72 74 72 59  
Fax : +33 4 72 82 77 13  
Eml.:alain.frichet@framatome-  
anp.fr

## **GERMANY**

Dr. Heinz G. SONNENBURG  
GRS mbH  
Forschungsgelaende  
D-85748 GARCHING

Tel.: +49 89 320 04 578  
Fax: +49 89 320 04 599  
Eml.: son@grs.de

Dr. Lothar HEINS  
Framatome ANP GmbH  
P.O. Box 3220  
D-91050 Erlangen

Tel: +49 9131 1892068  
Fax: +49 9131 184799  
Eml: lothar.heins@framatome-anp.de

Mr. Mathias BRETTNER  
Physikerbuero Bremen  
Landweg 6  
D-28203 Bremen

Tel.: +49-421-323571  
Fax: +49-421-328719  
Eml: m.brettner@physikerbuero.de

Mr. Siegfried LANGENBUCH  
GRS mbH  
Forschungsgelaende  
D-85748 GARCHING

Tel.: +49-89-32004-424  
Fax: +49-89-32004-599  
Eml.: lab@grs.de

**HUNGARY**

Dr. Laszlo MAROTI  
Deputy Director  
Atomic Energy Research Institute  
Konkoly Thege 39  
P.O. Box 49  
H-1525 BUDAPEST 114

Tel.: +36 1 275 4090  
Fax: +36 1 395 9293  
Eml.: hozer@sunserv.kfki.hu

**JAPAN**

Dr. Takehiko NAKAMURA  
Senior Engineer  
Fuel Safety Research Laboratory  
Department of Reactor Safety Research  
Japan Atomic Energy Research Institute  
Tokai-mura, Naka-gun, Ibaraki-ken 319-1195

Tel.: +81 (29) 282 6386  
Fax: +81 (29) 282 5429  
Eml.: take@nsrr.tokai.jaeri.go.jp

Mr. Katsuichiro KAMIMURA  
Senior Manager - Nuclear Fuel Department  
NUPEC  
6th Floor, Fujita Kanko Toranomom Bldg.  
3-17-1 Toranomom  
Minato-ku, Tokyo 105-001

Tel: +81 3 4512 2671  
Fax: +81 3 4512 2699  
Eml: kamimura@nupec.or.jp

Mr. Tetsuo NAKAJIMA  
Senior Chief Engineer  
Institute of Nuclear Safety  
Nuclear Power Engineering Corporation (NUPEC)  
7th Floor, Fujita-Kanko Toranomom Bldg. 3-17-1  
Toranomom, Minato-ku  
Minato-ku, Tokyo 105-0001

Tel: +81 (3) 4512 - 2742  
Fax: +81 (3) 4512 - 2799  
E-mail: nakajima@nupec.or.jp

**KOREA (REPUBLIC OF)**

Dr. C. B. LEE  
Principal Research Scientist  
Korea Atomic Energy Research Institute  
P.O. Box 105  
Yusung, Taejon 305-600

Tel: +82 42 868 2129  
Fax: +82 42 868 8868  
Eml: cblee@kaeri.re.kr

Dr. Sun-Ki Kim  
Senior researcher  
Korea Atomic Energy Research Institute  
P.O. Box 105  
Yusung, Taejon 305-600

Tel. : +82-42-868-8661  
Fax. : +82-42-861-8819  
Eml : kimsk@kaeri.re.kr

**RUSSIAN FEDERATION**

Professor Vladimir ASMOLOV  
Director RRC KI for R&D  
Kurchatov sq. 1  
Moscow 123182

Tel: (7-095) 196-9320  
Fax: (7-095) 196-1702  
Eml: asmolov@nsi.kiae.ru

Dr. Larisa YEGOROVA  
Head of Department NSI RRC KI  
Kurchatov sq. 1  
Moscow 123182

Tel: (7-095) 196-7283  
Fax: (7-095) 196-1702  
Eml: yegorova@nsi.kiae.ru

Dr. Valery MALOFEEV  
Chief of Laboratory NSI RRCKI  
Kurchatov sq. 1  
Moscow 123182

Tel: (7-095) 196-7466  
Fax: (7-095) 196-1702  
Eml: malofeev@nsi.kiae.ru

Mr. Iouri Vladimirovch PIMENOV  
Senior Expert  
J - Stock Company "TVEL"  
B.Ordynka 24/26  
101000 Moscow

Tel.: 007 095 239-41-98  
Fax: 007 095 239-44-04  
Eml: pimenov@tvel.ru

Ms. Olga Artiemovna NETCHAEVA  
Senior Researcher  
FSUE A.A. Bochvar VNIINM  
P.O.Box 369 VNIINM  
123060, Moscow

Tel.: 007 095 190-62-36  
Fax : 007 095 190-51-16,  
095 196-65-91  
Eml: olja@bochvar.ru

Mrs. L. N. ANDREEVA-ANDRIEVSKAYA  
Senior Researcher  
VNIINM  
123060 Moscow, P.O. Box 369

Tel.: 007 095 190-62-36  
Fax: 007 (095) 190-51-16,  
(095) 196-65-91  
Eml.: aaln@bochvar.ru

**SPAIN**

Mr. M. José Manuel CONDE LOPEZ  
Head, Nuclear Engineering D.  
Consejo de Seguridad Nuclear  
Justo Dorado, 11  
28040 MADRID

Tel.: +34 91 346 02 53  
Fax: +34 91 346 05 88  
Eml.: jmcl@csn.es

Mr. José M. REY  
Consejo de Seguridad Nuclear  
c/Justo Dorado, 11  
28040 Madrid

Tel.: 34-91-3460215  
Fax.: 34-91-3460215  
Eml.: jmrg@csn.es

Dr. Luis HERRANZ  
CIEMAT  
Dept. of Nuclear Fission  
Avda. Complutense, 22  
E-28040 Madrid

Tel: +34 91 3466219  
Fax: +34 91 3466233  
Eml: luisen.herranz@ciemat.es

Dr. Manuel QUECEDO  
Fuel Rod Technology  
ENUSA  
Santiago Rusiñol 12,  
28040 Madrid

Tel.: 34-913474264  
Fax: 34-913474215  
Eml: mqg@enusa.es

#### **SWEDEN**

Mr. Jan IN DE BETOU  
Swedish Nuclear Power Inspectorate  
SKI  
SE-10658 Stockholm

Tel.: +46 8 698 8459  
Fax: +46 8 661 9086  
Eml.: jan@ski.se

Mr. David SCHRIRE  
Studsvik  
SE-611 82 Nyköping

Tel.:+46-155-22 16 30  
Fax.:+46-155-26 31 56  
Eml: david.schrire@studsvik.se

#### **SWITZERLAND**

Dr. Willem VAN DOESBURG  
Swiss Federal Nuclear  
Safety Inspectorate (HSK)  
Hauptabteilung fuer die  
Sicherheit der Kernanlagen  
CH - 5232 VILLIGEN-HSK

Tel.: +41 56 310 3862  
Fax: +41 56 310 4979  
Eml.: willem.vandoesburg@hsk.  
psi.ch

Dr. Claude MAEDER  
Swiss Federal Nuclear  
Safety Inspectorate (HSK)  
Hauptabteilung fuer die  
Sicherheit der Kernanlagen  
CH - 5232 VILLIGEN-HSK

Tel.: +41 56 310 3811  
Fax: +41 56 310 38 54  
Eml.: claude.maeder@hsk.psi.ch

Mr. Frank HOLZGREWE  
Nuklearingenieur  
Ressort Physik  
BKW FMB Energie AG  
Kernkraftwerk Mühleberg  
CH-3203 Mühleberg

Tel.: ++41 (0)31 754 74 72  
Fax: ++41 (0)31 754 71 25  
Eml: frank.holzgrewe@bkw-fmb.ch

#### **UNITED KINGDOM**

Mr. J.R. JONES  
British Energy Ltd.  
Barnet Way Eml.:  
Barnwood  
Gloucester GL4 3RS.

Tel.: + 44 1452 65 33 86  
Fax: + 44 1452 65 22 06  
john.r.jones@british-energy.com

**UNITED STATES OF AMERICA**

Dr. Ralph O. MEYER  
Office of Nuclear Regulatory Research  
USNRC  
Washington DC 20555

Tel.: +1 301 415 6789  
Fax: +1 301 415 5160  
Eml.: rom@nrc.gov

Dr. Rosa YANG  
Nuclear Power Division  
EPRI  
3412 Hillview Ave P.O. Box 10412  
PALO ALTO, CA 94303

Tel.: +1 650 855 2481  
Fax: +1 650-855 1026  
Eml.: ryang@epri.com

Mr. David J. DIAMOND  
Head  
Nuclear Energy and Infrastructure Systems Division  
Brookhaven National Laboratory  
BNL-130 Upton, NY 11973-5000

Tel.: +1 631 344 2604  
Fax: +1 631 344.3957  
Eml: diamond@bnl.gov

**International Organisations**

***OECD/Halden Reactor Project***

Dr. Wolfgang WIESENACK  
Acting Project Manager  
OECD Halden Reactor Project  
Institut for Energiteknikk  
Os Alle 13 - P.O. Box 173  
N-1751 HALDEN

Tel.: +47 (69) 21 2200  
Fax: +47 (69) 21 2201  
Eml.: wolfgang.wiesenack@hrp.no

***OECD Nuclear Energy Agency, Issy-les-Moulineaux***

Mr. Miroslav HREHOR  
OECD Nuclear Energy Agency  
Le Seine St. Germain  
12, boulevard des Iles  
F-92130 ISSY-LES-MOULINEAUX

Tel.: +33 1 45 24 10 58  
Fax: +33 1 45 24 11 10  
Eml.: miroslav.hrehor@oecd.org

Dr. Carlo VITANZA  
OECD Nuclear Energy Agency  
Le Seine St. Germain  
12, boulevard des Iles  
F-92130 ISSY-LES-MOULINEAUX

Tel.: +33 1 45 24 10 62  
Fax: +33 1 45 24 11 10  
Eml.: carlo.vitanza@oecd.org