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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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Working Group on the Analysis and Management of Accidents

Summary Record of the First Technical Meeting of the WGAMA Task Group on Core Exit Temperature (CET) Effectiveness in Accident Management

Held on 24th-25th April, 2008, at KFKI Atomic Research Institute, Budapest, Hungary

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The 1st
Technical Meeting of the WGAMA Task Group on Core Exit Temperature (CET)
Effectiveness in Accident Management
April 24-25, 2008
KFKI Atomic Research Institute, Budapest

Summary

The main objective of the 1st Core Exit Temperature (CET) effectiveness in Accident Management (AM) Task group was to exchange and to discuss information related to:

- the country status regarding the use of CET in AM,
- the availability of experimental data for confirmation of use of CET in AM and the ways to get it,
- the possible effect of CET thermocouples location (both in test facilities and in Nuclear Power Plant) on CET readings.

On the basis of this technical discussion, the CET effectiveness Task group could draft a questionnaire to be distributed to the WGAMA members for answers by end of June 2008. The answers will be compiled and analysed and then discussed during the next CET effectiveness Task group meeting on September 22nd, 2008.

In the following, the results from the discussions on the individual agenda items will be summarized.

A. Welcome, opening remarks (agenda item 1)

The CSNI/ WGAMA Chairman, Mr. Ivan Tóth, welcomed the participants in the premises of the Hungarian Academy of Sciences KFKI Nuclear Energy Research Institute. He elaborated on the missions and activities of the Institute in the area of nuclear technology and especially in maintaining competence in nuclear safety and distributed to the participants the Institute Progress Report on Research Activities for 2006.

The NEA secretariat thanked the KFKI Nuclear Energy Research Institute for hosting the meeting, and the participants to be so motivated to participate to this first CET effectiveness Task group meeting.

B. Agenda (item 2 of the agenda)

The proposed agenda for this meeting (see Appendix 1) was agreed upon with the replacement of the Switzerland report (apologies were received from Mr. Drier (PSI)) by a presentation by Mr. Umminger from AREVA-Germany.

C. Review of the Task group mandate and CSNI expectations (item 3 of the agenda)

The NEA Secretariat recalled the mandate of the Task group with reference to the CAPS. The objective and the justification of the activity were pointed out. The CSNI is expecting a status report covering the collection and review of the design basis of CET application for AM procedures in different countries as well as a review of relevant experimental results with emphasis on time delay between CET reading and core temperature rise. A co-operation with ROSA and PKL-2 Projects would be beneficial in order to draw

relevant conclusions and recommendations for possible further work on this issue. The final report is expected to be submitted to PRG CSNI approval in October/December 2009.

On practical level, nominations were received from AREVA-France, AREVA-Germany, Belgium, Hungary, Italy, Japan, Korea, Slovenia, Spain and Switzerland. This provides the adequate number of participants for a core group which includes utilities, designers/vendors, research institutes, technical support organizations and regulators.

D. Review of the CET effectiveness issue (item 4 of the agenda)

Mr. Tóth reviewed the CET effectiveness issue by addressing its background, CET set points used in AM and several experimental tests (LOFT, PKL, LSTF) which analysis has shown that CET thermocouples reading are delayed and/or do not reflect cladding temperature rise.

Concerning the background of the issue, Mr. Tóth recalled that the CET was raised by O. Sandervag (SKI) in the November 2006 ROSA Project meeting after witnessing the test T6-1. During the May 2007 ROSA Project meeting, the CET issue was addressed by two presentations: "the role of the core exit thermocouples in accident management", and "Performance of Core Exit Temperatures for Accident Management Action in LSTF 1.9% Top Break LOCA Test (supplemental report for Test 6-1)". The second presentation was repeated during the 2007 WGAMA annual meeting. Mr. Tóth used these two presentations for his review.

It was noted that the test 6-1 results showed that the core uncovery had started significantly early before the CET thermocouples showed superheating and that the temperature increase rate was higher in the core than in the CET. The results suggested that the response of the CET could be inadequate to initiate the relevant AM actions. Moreover, 4 LOFT experiments have been analyzed; they confirm that there may be scenarios in which CET indications would be inadequate to initiate the corresponding AM actions. Possible reasons and hypothesis to explain this observation have been then mentioned; they are mainly related to a possible cooling of the CET thermocouple by Steam generators reflux water, persistence of liquid film on the CET thermocouples surface combined with low steam velocities, or thermodynamic non-equilibrium between steam and water droplets.

Mr. Tóth recalled that the CET is widely used in AM though CET set points may vary among reactor types and designs. However, since the CET is important for AM actions initiation, in particular for those countries that have not implemented other means (e.g., water level tracking) in conjunction or in place of CET, it is important to understand the behavior of the CET in order to assess its reliability.

E. Overview of the country's status regarding CET use in AM (items 5 and 11 of the agenda)

Belgium report:

Mr.Keijers (Tractebel) recalled the nuclear power fleet in Belgium. There are 7 operating reactors distributed in two sites: Doel (4 reactors) and Tihange (3 reactors). Doel units 1and 2 are Westinghouse 2-loop reactors; Tihange 1, Tihange 2 and Doel 3 are Framatome 3-loop reactors; Tihange 3 and Doel 4 are Westinghouse 3-loop reactors.

Concerning the Emergency Operating procedures (EOPs) used in Belgium, it was noted that all the Belgian reactors use Westinghouse type EOPs, except Tihange 1 which uses Instructions of Accident Management which is EDF procedures based. All the reactors use Severe Accident Management Guidelines (SAMG).

For each type of procedures, Mr. Keijers provided the CET set point to initiate AM measures. It was noted that the transition between EOPs and SAMG in Westinghouse type procedures refers to a CET > 650°C,

while the entry in SAMG for Tihange 1 requires more complex decision based on a graph. The Post Accident Monitoring System instrumentation includes the measurement of the following parameters:

- Primary pressure and primary temperatures (CET by use of 5 out of x, hot leg temperature, cold leg temperature, sub-cooling margin);
- Steam generators pressure and water level;
- Containment pressure.

It has to be pointed out that the instrumentation does not include water level measurement in the Reactor Pressure Vessel (RPV).

Mr. Keijers ended his presentation by raising some questions, in particular about the representativeness of the CET during the ROSA/LSTF Test 6-1 at reactor scale and for other transients.

Hungary report:

The presentation was provided by Mrs . Eva Tóth (PAKS NPP). She recalled that the PAKS NPP includes 4 VVER-440/213 reactors which have the generic features of that type of reactors: 6 loops with horizontal Steam generators, main loop isolating valves, relatively small reactor core in a long reactor vessel, shrouded assemblies with thermocouple at assembly outlet, low linear power, large water reserves in the primary and secondary sides and a confinement structure with a Bubbler Condenser (2.5 bar design pressure).

Then, Mrs. Tóth addressed the EOPs status. EOPs are of Westinghouse type and they have been developed specifically for PAKS between 1997 and 2000, with support calculations and studies performed by KFKI Atomic Energy Research Institute. These EOPs have been validated on PAKS simulator and implemented on December 31, 2001. As for SAM strategies, they include the 3 classical key elements: prevention of core damage (by using EOPs), in-vessel retention or ex-vessel debris cooling, and release and containment management. It was noted that the SAMG should be based on the implemented plant modifications and measures and should be linked with the already implemented EOPs. The development of Westinghouse type SAMG which started in 2006 is near to be completed. The required hardware modifications will be made between 2008 and 2010 and the SAMG implementation on PAKS unit 1 is expected in 2011. No RPV water level measurement exists in PAKS NPP.

The role of CET in AM for PAKS was explained with a focus on specific concerns with the use of CET in AM:

- for the use of EOPs, a minimum of 5 CET indications are required to enter to the FR-C guidelines:

  - FR-C.2 “Response to degraded core cooling” is made when CET> 370°C; the corresponding action is an intensive secondary side cooling;

  - FR-C.1 “Response to inadequate core cooling” is activated when CET> 550 °C; the corresponding action is primary pressure reduction. The latter CET set point has been decreased from 650°C (W-generic set point) to 550 °C following the results of the PHARE 4.2.7.a/93 Project and KFKI Atomic Energy Research Institute calculations.

There are 216 thermocouples (Emerson, Heraeus type) available for CET, with operating narrow range (T core exit > 400 °C) and accident wide range (400 °C < Tcore exit < 600 °C). However, Mrs. Tóth mentioned that these ranges and limits might lead to some problems (in particular, 600 °C limit would not

allow unit staff to have enough time to finish steps in FR-C.1 guideline and thus to check effectiveness of operator actions; 0-600 °C range may not be sufficient to check core status after finishing FR-C.1).

- As for the role of CET in the use of SAMG, the Westinghouse proposal leads to the CET > 1100 °C as set point for the transition from EOPs to SAMG, given that a minimum of 3 CET indications is required.

This transition set point, not enough justified, has been questioned by VEIKI, PAKS NPP and KFKI experts who propose lower set points on the basis of different arguments. The answers to some questions within the present task may help to make the appropriate choice of CET set points.

Slovenia report:

Mr. Mühleisen recalled that Slovenia has only one NPP (Krsko) which is 2-loop Westinghouse 700 MWe PWR. Procedures are Westinghouse Owners Group based.

As for CET, there is no explicit regulatory requirement for CETs; however, I&C which may be used during Design Basis Accident (DBA) or Beyond Design Basis Accident (BDBA) has to be harmonized with WENRA requirements. The CET thermocouples (39 thermocouples in two trains) were replaced last time in 1999 when ICCMS system was installed to comply with NUREG-0737 requirements which fulfilment was verified.

The CETs are used in sub-cooling margin calculation, as core temperature measurements/indicators, for EOPs and SAMG and for core damage assessment. The CET thermocouples are K-type (Chromel-Alumel) and of "top mount design"; the quoted range is 0-1260 °C and the accuracy is ± 31 °F at 638 °F and ± 200 °F at 1202 °F. They are supposed to operate correctly till 650 °C.

In EOPS, CET thermocouples are used for:

- monitoring of core cooling critical safety function in combination with RVLIS (water level measurement),
- defining entry points for different core cooling sub-procedures/strategies,
- checks on success of core cooling strategies,
- actions related to core cooling within EOPs when CET> 650 °C,
- exit from EOPs to enter SAMGs if CETs > 650 °C and core cooling not successful.

The CET readings are the only available way to enter SAMG for which there is explicit warning that early entry in SAMG might impair the chances to re-establish core cooling before significant core damage.

Mr. Mühleisen presented the use in SAMG with the following insights:

- SAMG could be entered from 3 EOP sub-procedures, in each case provided CET > 650 °C,
- CET may be used within SAMG to determine need for injection in the RCS and exit conditions but there are also alternative methods of measurements/estimation,
- the CETs are not used within specific SAMG procedures except in the procedure defining SAMG exit conditions.

He completed his presentation by addressing limitations of the CETs in SAMG, for instance their lack of accuracy after significant core relocation or simply the fact that they might not be useable after severe core damage.

Spain report:

Mr. Alonso-Escós provided a status report on the use of CET in AM for Spanish NPPs. There are 8 reactors (2 BWR reactors and 6 PWR reactors) distributed among 6 NPPs. The BWR reactors are of General Electric (GE) design, whereas there are one KWU 3-loop reactor and 5 Westinghouse 3-loop reactors.

Concerning the AM, EOPs and SAMG exist for GE and Westinghouse reactors while only EOPs (Operating Manual and Accident Management Manual) seem to exist for the KWU reactor. The AM actions refer to the following means:

- reactor vessel level for BWR reactors,
- CETs plus RVLIS for Westinghouse reactors,
- CETs plus thermo-resistances binary sensors which detect only wet or dry conditions.

A detailed description of CET thermocouples and reactor vessel level was then given for both types of Spanish PWRs. For the CETs thermocouples, the description included the number of the thermocouples, their location and their temperature range. As for the reactor vessel level measurement (Westinghouse PWR) or tracking (KWU PWR), details were given concerning the monitorization range, the basis of the measurement or tracking and the location of the sensors when applicable.

Mr. Alonso-Escós completed his presentation by addressing in detail the main actions in the EOPs or the transition from EOPs to SAMG using CET set points as far as Westinghouse PWR type were concerned. He did the same for EOPs when addressing the KWU type reactor.

AREVA-Germany report:

Mr. Umminger provided a presentation on PKL experiments on AM procedures with focus on CET behaviour.

He first addressed the AM procedures used in German PWRs in case of total loss of SG feed-water supply or Station Blackout. In these two cases, the German AM procedures give preference to an early Secondary Side Bleed and Feed which is initiated when RCS is still filled with water (Pressurizer level high or first opening of Pressurizer safety valve). The Primary side bleed and feed is used if the secondary side bleed and feed fails or if it is no more effective. Primary side bleed and feed is used when the level in the RPV drops below reactor coolant line (RPV level probe) or when CET> 400 °C which is the latest point in time.

Before presenting examples of PKL experiments on AM procedures, M. Umminger described the modalities of activation of the secondary Side bleed and feed via Main Steam Relief Valves opening and secondary side water injection (passive feed from feed water line and feed water tank or active feed by mobile pump) and the associated criteria for initiation. The primary side bleed and feed is made according the classical way via the Pressurizer valves opening and water injection in the primary side by high pressure safety injection pumps and later by the accumulators. The initiation is made when the RPV level drops below the RCL or when superheating at core exit reaches 50 K.

Loss of feed water transient simulation on PKL was presented with two variants: “early” secondary side bleed and feed and “late” secondary bleed and feed. It was shown that while in the first case, the primary

temperature remains lower or equal to the saturation temperature, in the second case there is a significant temperature increase.

In the case of a "very late" secondary side Bleed and Feed, there is, as expected, a more significant temperature excursion, but with evidencing a difference in the temperature "seen" by the cladding tubes.

The access to relevant PKL experimental results was discussed. Mr. Umminger informed that most of relevant experiments have been performed for national needs with national funds. Therefore, an authorization should be given in order to disclose the results to the member of the Task group. It was concluded that the NEA Secretariat would prepare a letter for that purpose, on the basis of inputs from Mr. Umminger.

AREVA-France report:

Mr. Prior provided a detailed overview in which he addressed the scope of AM, the use of CET for the transition from the EOPs to SAM in different approaches (AREVA OSSA, WOG, EDF GIAG) and other uses of CET in AM.

Regarding the scope, he recalled that actions aimed at preventing or delaying core damage are dealt with in the frame of the EOPs; the effectiveness of preventive measures can be quantified using level 1 PSA. Mitigative actions are aimed at mitigating core damage and protecting fission product boundaries. Guidance is given in SAMG which is structured but not rigid procedures. Similarly, the effectiveness of mitigative measures can be quantified using level 2 PSA. The reactor state (from power operation up to RCS open) is an important parameter which should be taken into account for both EOPs and SAMG.

Mr. Prior addressed also the generalized state approach and the related EOP coverage, through the example of EDF emergency procedures.

As for EOP-SAMG transition, Mr. Prior highlighted the issues which affect the choice of transition criteria such as:

- termination of EOPs or simultaneous usage,
- EOP and SAMG origin/approach,
- Scenario dependence, especially pressure,
- phenomenology of core coolability and reflood,
- decision making authority and organisation,
- time windows,
- analytical and modelling capabilities,
- ease of use.

He illustrated the effect of pressure on the EOP-SAMG transition through the analysis made for the AREVA OSSA entry conditions. He then compared the approaches used for EOP-SAMG transition.

Since most existing approaches use core exit temperature at reactor power state and since CET thermocouples are not available in many reactor shutdown sates, an alternative to CET is needed. Some of alternatives exist:

- containment radiation which depends on certain factors (spray system, RPV head on/off, shielding effects etc.) and which is difficult to calculate (requires to know the relation between measured radiation and % of core damage);
- water level measurement which requires an adequate instrumentation;
- hydrogen concentration in the containment for which timing and dependence on scenario/operating state are important,
- ex-core neutron flux which requires correct interpretation.

Currently, SAMG are being extended to cover reactor shutdown states. Alternatives to EOPs-SAMG transition based on CET have been already adopted in Koeberg (containment radiation versus time with 10% gap release), AREVA OSSA and EDF GIAG (containment radiation).

Mr. Prior completed his presentation by addressing other uses of CET in EOPs and in SAMG.

Italy report:

Mr. Muellner focused his presentation on the Pisa University activities relevant to the Task group on CET effectiveness. These activities have been conducted in the frame of TACIS Project 30303 which covers VVER-1000 and RBMK. In this project, Pisa University is involved jointly with 3 Russian organisations (EREC, Gidropress and Kurshatov Institute).

The project included:

- an experimental campain of 16 tests conducted on PSB-VVER with relevance to AM;
- Cathare 2 and Relap 5 validation for VVER-1000 AM;
- RBMK safety analysis and proposal for ICM to avoid Pressure Tube (PT) failure following Fuel Channel (FC) blockage.

Concerning RBMK, a blockage of FC has been simulated with Relap 5. The analysis of the results has shown that this event causes unavoidable Pressure Tube rupture, possible radiation doses to personnel and also cost for the NPP associated with the shutdown, cleaning and reparation. The project partners proposed an ICM system which may be suitable for all events associated to flow reduction. The ICM instrumentation consists of a thermocouple at FC outlet (CET) and a flow-meter at FC inlet. The ICM scram signal corresponds to the simultaneous occurrence of high temperature (Tsat + 10 K) at FC outlet and low flow (Nominal flow rate – 30%) at the FC inlet. The ICM effectiveness was shown through code simulation and FC blockage is detectable. However, no investigation has been performed regarding the technological aspects of the proposed scram signal (e.g., its interaction with other safety or operational systems).

As activities performed on PSB-VVER, Mr. Muellner commented the 16 tests conducted on the test facility with relevance to accident management. These tests include loss of feed water, small break LOCA, Primary to secondary leak, station blackout and Steam line break with different options regarding systems availability.

The results which were used for Cathare 2 and Relap 5 validation for VVER-1000 may be also of interest to the activity of the CET effectiveness Task group. However, the question of relevance of the tests for the Task group was raised since AM actions are initiated at low temperature in order to avoid core heat-up.

It was agreed that the Secretariat would send a letter to the European Commission, through Pisa University, in order to get some relevant results.

F. Available test data and discussion of the effect of CET thermocouples location (agenda items 12 and 13)

The discussion of the Task group was based on the following highlights prepared by the Chairman:

1- Task group main focus with regard to CET:

Should we consider the application of CET as an entry point for specific EOPs or only for the transition from EOPs to SAMG?

2 – Design basis for CET application:

This design is based on scoping analysis actions with the aim to demonstrate that with the selected set points, the foreseen actions can assure restoration of core cooling. Was the CET time delay considered in these scoping analyses? If yes, what was the value? If no, a review of the CET design basis is needed and should consider the importance of the CET time delay and its value.

3 – Possible practical approach:

It was proposed to review the effect of CET time delay on each type of action based on CET set point; this may eliminate a number of cases. If for a given case, the CET time delay threatens conclusions, a review of CET impact is needed for this special case on the basis of relevant test data and by addressing the effect of CET thermocouples location.

The Task group discussed the proposal with the following insights:

- The issue of EDF participation to the Task group was raised again; even if the CET effectiveness issue is closed for EDF, its experience and its participation to the Task group may help others to resolve the issue.

- Discussion on the meaning of CET time delay: how to reflect the difference between the CET reading and the cladding temperature? By a time delay for a fixed temperature set point, given that time conditions operator actions?

- Discussion about the CET definition and to which extent the models in the computer codes used for scoping calculations are validated for CET calculation?

- Test data issue:

  - The Task group agreed that the availability and the analysis of relevant data is an important part of the proposed approach;

  - a letter should be addressed by the NEA Secretariat to PKL Project, ROSA Project and to the EC (via Pisa University) in order to have relevant data to address CET effectiveness issue; this data should include CET readings, clad temperature and information about CET thermocouples location and possible phenomena likely to impact CET readings;

  - the Chairman will ask O. Sandervag to summarise relevant LOFT tests and Z. Hózer to address Quench tests.

G. Draft questionnaire to be distributed to WGAMA members (agenda item 14)

Based on the previous discussion, the Task group was able to draft the following questionnaire to be distributed to the WGAMA members:

1- Is CET used for accident management in your country?

2- If yes, for what purposes?

3- If you have set points for CET use, please provide the values and describe the basis.

4- How do you account of the fact that the CET is not the cladding temperature?

5- In case you perform supporting calculations, please describe the way you model the CET. Have you made comparison with experiments to support the approach?

6- Do you have any specific concerns associated with the use of CET in accident management?

The NEA Secretariat will complete the questionnaire by introducing the context of the activity.

H. Further actions and next meeting (agenda item 15)

Based on the current outlook, the following time schedule is envisaged:

May 2nd, 2008	Questionnaire completed and distributed to the Task group members for comments by May 9th, 2008.
May 16th, 2008	Questionnaire distributed to WGAMA members for comments by June 30th, 2008.
May 16th, 2008	Letters to be sent by the NEA Secretariat to PKL Project, ROSA Project and to the EC via Pisa University to make available.
September 15th, 2008	Distribution by Mr. Prior of a synthesis of the answers to the questionnaire to the Task group members.
September 22nd 2008	Next CET Task group meeting

I. Available documents

All presentations made during this meeting, as well as other relevant documents, will be made available in a CD which will also include the Summary Record of the meeting.

Appendix 1

First Meeting of the WGAMA CET Activity
KFKI Atomic Energy Research Institute, Budapest, April 24-25, 2008.

April 24th, 2008.

09:30 – 09:45	Welcome (I. TOTH) Opening remarks (NEA Secretariat)
09:40 – 09:45	Adoption of the Agenda (NEA Secretariat)
09:45 – 10:15	Review of TG mandate and CSNI expectations (NEA Secretariat)
10:15 – 10:30	Break
10:30 – 11:00	Review of the CET effectiveness issue (I. TÓTH)
11:00 – 11:45	Overview of the country's status regarding CET use in AM – Belgium report
11:45 – 12:30	Overview of the country's status regarding CET use in AM – Hungary report
12:30 – 13:30	Lunch
13:30 – 14:15	Overview of the country's status regarding CET use in AM – Slovenia report
14:15 – 15:00	Overview of the country's status regarding CET use in AM – Spain report
15:00 – 15:45	Overview of the country's status regarding CET use in AM – Switzerland report
15:45 – 16:00	Break
16:00 – 17:00	Overview of the Westinghouse background of the issue and possibly overview of France status regarding CET use in AM – R. PRIOR report
17:00 – 17:45	Overview of the country's status regarding CET use in AM – N. MUELLNER report
17:45	Adjourn.

April 25th, 2008.

9:30 – 10:30	Presentations- discussion on available test data for confirmation of use of CET in AM
10:30 – 10:45	Break
10:45 – 11:45	Presentations and discussion of the effect of CET location (both in test facilities and in NPP) on CET reading.
11:45 – 12:30	Discussion of the content of a questionnaire on CET to be distributed to the WGAMA members.
12:30 – 13:00	Further actions and next meeting
13:00	End of the meeting.

Appendix 2

LIST OF PARTICIPANTS

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Apologies were received from:

- **Mr. NAKAMURA, JAEA, Japan**
- **Mr. HUH, KINS, Korea**
- **Mr. DREIER, PSI, Switzerland.**