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Review Article

International Standard Problems and Sr Loss-of-Coolant Accident (SBLOCA)

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Abstract

Best-estimate thermal-hydraulic system codes are widely used tc power plants and also used in the design of advance reactors. Ev these codes can be accomplished by comparing the code predicti different test facilities. OECD/NEA Committee on the Safety of Nu last twenty-nine years, some forty-eight international standard different fields as in-vessel thermal-hydraulic behaviour, fuel be release and transport, core/concrete interactions, hydrogen distri behaviour. 80% of these ISPs were related to the working domain behaviour (PWG2) and were one of the major PWG2 activities for contribution that ISPs have made to address nuclear reactor sa overview on the subject of small break LOCA ISPs is given in th group. In addition, the relevance of small break LOCA in a PW reorientation of the reactor safety program after TMI-2 accident integral test facilities, LOBI, SPES, BETHSY, ROSA IV/LSTF and rupture transient in the DOEL-2 PWR (Belgium) were the basis o which deal with the phenomenon typical of small break LOCAs in these small break LOCA ISPs are identified in relation to code capabilities, possibility of scaling, and various additional aspects. some safety-related issues.

1. Introduction

Large transient thermal-hydraulic system codes are widely used t
power plants and also used in the design of advanced reactors. Ev
these codes can be accomplished by comparing the code predicti
different test facilities. In this respect, parallel to other national ar
Agency (OECD/NEA) Committee on the Safety of Nuclear Installati
some fourty eight international standard problems (ISPs) [1, 2].
organized in 1975 on the famous "Edwards blowdown pipe" ex
fields as in-vessel thermal-hydraulic behaviour, fuel behaviour un
transport, core/concrete interactions, hydrogen distribution an
Roughly, 60% of these ISPs concerned the thermal-hydraulic beha

The main goal of ISP exercises is to increase confidence in the vali
in assessing the safety of nuclear installations. These tools may
extremely complex. Therefore, the ISPs were considered as an e
judgment about the code/user capabilities on an international ba
computer codes with respect to a given physical problem may be
among each other.

While the developmental assessment still belongs to the organis
considered as a complementary activity, assessing the codes thro
developers and covering much wider ranges, specifically in ter
parameters.

The objectives of the ISP may be summarized as

- (i) to contribute to better understanding of postulated event
- (ii) to compare and evaluate the capability of codes (mainly l
- (iii) to suggest improvements to the code developers,
- (iv) to improve the ability of code users,
- (v) to address the so called scaling effect.

Standard problems are performed as "open" or "blind" (dou
participants know the results of the experiment in detail before pe
the results are locked until the code users submit the calculation r
exercise consists of a "blind" one for which no other experir
published or made available to the ISP participants before submis
are keenly encouraged to run post test calculations when the e
calculations are sensitivity studies, where various options and/or
the results, also to better understand the reasons for eventual
results and experimental data.

As mentioned in [3], both integral and separate effect experime
estimate codes are preferably used. The reader will also find in
organisation of an ISP exercise.

A global review and synthesis on the contribution that small breal
safety issues was initiated by the principal working group no. 2 (P\
the PWG2, an action has been put, during the thirteenth meetin
Behaviour (TG-THSB), to carry out this review and synthesis work
this synthesis work, a short overview report was written on this su

order to limit the effort, five ISPs were selected for this evalua
scenarios; ISPs in which similar phenomenon to small break LOCA

(i) *ISP 18:* LOBI Mod2 1% small break LOCA [5];
(ii) *ISP 20:* Doel 2 steam generator tube rupture event [6];
(iii) *ISP 22:* SPES-simulating loss of feedwater transient in Ita
(iv) *ISP 26:* ROSA-IV LSTF 5% cold leg small break LOCA exp
(v) *ISP 27:* BETHSY 0.5% small break LOCA with loss of high

The ISPs 18, 22, and 27 were "blind" exercises, while the ISPs "oldest" ISP retained in this review and synthesis work, since su transition process between the first generation codes (i.e., RELAP codes (e.g., TRAC, RELAP5, ATHLET, CATHARE). It is to be note previous to ISP-18, for example, LOFT and semiscale small break review process due to advancement of the codes relative to the ap Moreover, at that time some of these new codes were in their d that, since 1985, the objectives of ISP were slightly changed developmental phase.

While the ISP 22 initiating event is not a small break, it has phenomena observed during the experiment are similar to those might give the opportunity to fill the gap between BETHSY and LOE

ISP 20 has been retained in this evaluation as far as scaling effe unique exercise based on a transient occurring in a full-scale two-l

Other internationally conducted research programmes in this same considered, including ISPs, for example, ISP 25 and ISP 33. experiments analyzed by a CEC devoted task group. However, r homogeneity for the discussed transients (i.e., ISP 25 is based behaviour of WWER plants; LOFT is a nuclear facility scaled dow BETHSY, and LSTF; in addition most of the LOFT, LOBI, and LSTF community) supported the conclusion to restrict the investiga contributions given by the above mentioned programmes in this sa

The outcome from each considered ISP and in particular the eval predicted system behaviours are described in detail in the "fi therefore will not be repeated here. Identically, this synthesis wo been separately addressed and analyzed in detail in [11].

In this paper, some of the aspects addressed in [4] will be summa learned from the small break LOCA ISPs. Section 2 will give an c issue. Main phenomena and relevance of small break LOCA to reac 3. A short overview of ISPs and expected technical findings are de the involved facilities and plant and a description of the differen relevant ISP statistics. Section 8 presents the "lessons learne conclusions and recommendations. This also constitutes the main c

2. Origin of Small Break LOCA Issue (System Therm

In early 1970s, former US Atomic Energy Commission convened relation to the effectiveness of systems to mitigate the consequ reactor, in case it happens. Ultimately, after extensive public heari

to provide a set of specific requirements for computer codes for E
[12, Appendix K], requiring ECCS meet established standards. Thi
accidents that would result from the loss of reactor coolant, at a ra
makeup system, from breaks in pipes in the reactor coolant press
in size to the double-ended rupture of the largest pipe in the react
10 CFR 50.46 are applicable to both large and small break LC
temperature, cladding oxidation, and hydrogen generation mus
Calculations of ECCS performance using the conservative prescript
LOCA generally being the most limiting accident. At the time, t
support code development for large break LOCA and also some lim

The March 1979 accident at the Three Mile Island Unit 2 (TMI-2
water reactor safety research programmes and also regulatory cha
an event given significantly less attention because of the major
Consequent to TMI-2, small break LOCA and plant operational tra
simulation of the natural circulation phenomena in the primary loo
counter-current flow regimes, is of primary importance to the th
during such transients. Since these phenomena are significantly de
tests for a primary system geometry representative of operat
operational facilities were modified to carry out small break LOCA
and constructed (see Section 4). It is to be noted that unlike the l
a small break LOCA can evolve in a variety of ways. Operator ac
and location will have a bearing how the small break LOCA scenari
system behaviour during a small break LOCA, a best-estimate code
these factors into account. These codes are also needed to be as
been successfully assessed against data from a large number of sc
ultimate repository of all previous thermal-hydraulic safety resea
Section 4).

3. Small Break LOCA in a PWR with Relevance to Nu
Phenomena

The major characteristic difference between a small break and a la
and pressure variations with time. In general, small break LOCAs
be tens of minutes to several hours at the lower end of the break s
which the primary system remains at a relatively high pressure ar
are tripped, either automatically or manually, gravity-controlled
dominate the flow and distribution of coolant inside the primary sy
or not the core uncovers and is recovered or reflooded, depends
break, but also on the overall behaviour of the primary and secon
by both automatic and operator initiated mitigation measures. In
break is slower compared to events after a large break. This allows
interventions. Another principal difference is the domination of gra
the large breaks.

It is to be noted that there is no unique path of development of
scenarios may change drastically by many factors such as the re
generators, such as TMI-2), the break size, the core bypass size
directly into the core upper structure without passing through the
interactions. As an example, the primary circulation pumps may b
or they may be allowed to run and circulate the coolant through
can make a large difference in the nature of discharge flow, e

inventory in the system after one hour or so in the transient. Ano through the steam generators. The secondary side of steam gene can be used for a controlled heat removal. It is also possible to bleed" process (on the primary side). Either of these actions will It is not the intent in this section to provide a catalogue of a accidents. But it is important to note that an adequate set of mod will be equally adequate for all other relevant scenarios. This is be but their interactions and timing of various developments change i the integral system behaviour during a small break LOCA, a b capabilities to take these factors into account.

During a PWR small break LOCA, there is the potential for three di loop seal formation and the manometric core liquid level depress clearing and break uncovery mitigate this heat up. The second he loop seal clearing and is caused by a simple core boiloff. During th accumulator set point and the steam produced by the core boiloff occur during this period are mitigated by the reflood from the accu following depletion of the accumulator tanks and before LPIS inje accompanying the accumulator injection is a decrease in the on possible heat up occurs before the LPIS primary pressure set poi Various factors affect the magnitudes of the three potential core direction and location, availability of HPIS, and the degree of up magnitudes of the core heat ups may vary, ECCS performance m 50.46 [12] is not exceeded.

The interested readers can obtain further details on small break LC

4. A Short Overview of ISPs and Technical Domains

A compilation of all ISPs performed between 1975 and 1997 can l and an extended list of ISPs (from 1975 to 2007) is also provided i

Table 1: List of CSNI international standard pr

The very first ISPs from 1975 to roughly 1980 focused on LO concerns of that time. We find there ISPs based on separate effe test, Battelle blowdown test, tube reflooding test ERSEC) and experiments for PWRs at that time, that is, SEMISCALE and LOFT.

After Three Mile Island (TMI-2) accident, ISPs started to move included ISPs on LOFT L3 small break LOCA series tests for PWRs break tests were still selected: PKL reflooding test, as reflooding v it was a significant "concluding" nuclear test for large breaks.

During this period (beginning 80s), two ISPs were initiated in a domain of thermo-mechanical fuel behaviour during LOCA. These PHEBUS LOCA test (nuclear).

In parallel to the ISPs dealing with the primary circuit, ISPs (in beginning of the 80s on containment experiments either system e small scale experiment (AAEC-Australia). These ISPs covered larg 80s by ISPs on HDR containment tests (large break in PWR) and M

During the second half of the 80s and during the beginning of th characterized by a full and coherent series based on the experime to well study small break and transient situations including ope SPES, ROSA IV, BETHSY facilities for PWRs (lessons learned from t included in this paper), and PIPER-ONE facility for BWRs. Besid noncondensable gases on reflood was performed (ACHILLES), and organized in 1988 on the DOEL 2 steam generator tube rupture ev

End of the 80s, the interest of ISPs moved clearly to the severe based on CORA (nonnuclear) and PHEBUS SFD (nuclear). Core c (SURC4 and BETA2). Containment questions and especially hydrog HDR and one ISP based on NUPEC test. In addition, an ISP was fission product behaviour with simulants.

One of the extensions of domain covered by ISPs is constituted PACTEL ISP (thermal-hydraulics) and CORA VVER ISP (Core degrad

In continuation of ISPs on thermal-hydraulics and severe accident BETHSY and steam explosions with an ISP on FARO. STORM and R in primary circuit and iodine behaviour in containment under sev assess boron dilution models.

Recent ISPs are PANDA test with six different phases related to reactors; QUENCH-06 and PHEBUS FP-1 tests for severe core deg for containment thermal-hydraulics.

This overview shows the extraordinary large range of technical d domains reflect of course the successive changes in the area of demonstrates also that the concept of ISP initiated in the therr technical areas, is certainly very productive and useful. We will, in specific subject of small break LOCA what are the outcomes and th explain its success.

5. The Expected Technical Findings from ISP Activit

The basic material of the technical findings from ISP activity is ma codes by several code users of a given physical experiment. From made which we will now review.

(i) The first class of comparisons is the comparisons between comparisons are evidently contributing to the code assessment. should be emphasized.

(a) This assessment belongs of course to the “independe

large number and very large variety of participants to ISPs, th
most accentuated that we can afford. For those who are think
important feature, the results of ISPs are unique.

(b) The number of code calculations in the comparison bet
certainly the largest that we can imagine on a single test. Almo
of financial limitations. Besides this number of calculations,
models used in the different codes. The comparisons with exp
effect of these models differences on the capabilities to predict
countries (and sometimes in the world) are represented durin
is then obtained on the status of the predictive capabilities of t

(c) It is clear that the large amount of work produced b
requires that no mistake should be done in the process. As a
very carefully selected. Therefore, it is very often one of the
experimental programme to which it belongs. The organisa
information be transmitted to the participants in a very co
country must do a very high control of test results and of doc
the OECD/NEA working groups to define standards for test do
the CSNI report no. 17 [3] and have shown to be quite genera
in several other areas than ISP. As the need arises, certain re
efforts made on the test selection, on the test control and
technical quality of very high level to the ISPs activities.

(d) The high-level grade of documentation obtained by f
selection of the tests based on their physical and safety signi
for inclusion in validation matrices. ISPs tests may often be
already wide distribution and their consequent availability is als

(ii) The second class of comparisons is constituted by the compa
experience of analysts that understanding and analysing the code
are most often required in order to give directions for the analyst
pertinence. A first group of indications is given by the analysi
experimental results, which has been discussed above. A second
results of different codes. This last group is often very valuable be
can be quite easily identified. Consequently, the analyst can focus
evaluate their relative capabilities in reference with the experime
give good opportunities for doing extensive analysis of this kind.

(iii) The last category of comparisons, which ISPs allow, is the com
by different users. The major differences between the calculations
users of the code and this effect has been called the "user effe
activity. It has been discovered very early by running the very fir
thermal-hydraulic advanced codes was expected to decrease this
shown that there was still a significant "user effect" with these a
been made on different ISPs and especially on ISP 26 [11]. In ac
have contributed largely to its understanding. ISPs are really pr
crucial subject. Even though some suggested ways to reduce the
are quite far from controlling it. This user effect has also appeared
hydraulics area where it has been discovered. In particular the se
the severe accidents area, have shown the importance of such an e

In the coming sections, specific analysis and further discussions w
transient ISPs.

6. Outline of Involved Facilities and Tests for SB-LO

6.1. Facilities and Plant Hardware

In this section, information is given concerning some hardware fea
Figure 1 shows the sketch of LOBI, SPES, BETHSY, and LSTF facilit

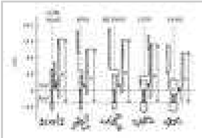


Figure 1: Sketch of the facilities considered fo

The relative elevations of important system components like core, the number of loops constituting the system is reported too. The n facilities and of the plant are given in Table 2. All the considered f pressure for both primary and secondary loops. The height scalir heads are properly simulated. The maximum allowed power is e volume scaling ratio only in the cases of LOBI and SPES. In oth around 10% of the nominal value. This scaling limitation prevent simultaneously rightly scaled temperatures and flowrates in nor generally made to preserve hot leg fluid temperature during alternatively, it is possible to preserve the cold leg fluid temperat preserved); as a consequence of the former choice, secondary sic than the reference plant nominal values (a real plant at hot stanc same behaviour, roughly 70 bar at secondary side); still, primary and head properly scaled, although in the case of BETHSY, prima the head in single phase flow conditions. The different criteria utili for defining the minimum elevation of the loop seal. In the faciliti adopted for the design of hot and cold legs piping also preserving t

Table 2: Relevant hardware characteristics o plant.

Nevertheless, the position of the hot leg axis with respect to the t reference nuclear power plant; in BETHSY, this position is preserve bottom line of the cold leg elevation to the bottom of active fuel, t axes. For all the multiloop facilities, each primary (and secon symmetrical thermal-hydraulic conditions occur in the various loop loop (intact) simulates three loops of the reference reactor and th parameters like pump geometrical configuration, presence, and c vessel) can play an important role in the considered test scenarios.

6.2. Outline of the Experimental Scenarios

The experiments A2-81, SP-FW-02, SB-CL-18, 9.1b, and the SGTR BETHSY facilities and Doel plant (Figure 1 and Table 2), were su CSNI and were discussed and approved at working group and organisations (i.e., proposing the exercise, writing the final repo given in Table 3. The procedures outlined in [3] for assignments of

Table 3: List of host organisations for small br

The main characteristics of the mentioned tests are reported in T LOCAs are listed in Table 5 [15], making use of a phenomena ma emergency core cooling thermal-hydraulics [15]. In the same ta facilities is provided, according to three judgment levels. For con possible use of this table, in the last two columns, an overall eva addition to their performances is reported, considering each of calculations [15].

Table 4: Main characteristics of the considerec

Table 5: Suitability of tests facilities, judgmen of RELAP5/Mod2 and CATHARE code capabilitie

The significant trends of variables with reference to the selected te of the experiments are given below.

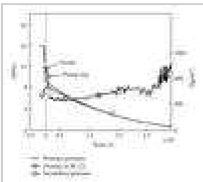


Figure 2: ISP-18 (LOBI): experimental trenc broken loop cold leg density.

ISP 18: The test in LOBI simulated a 1% cold leg break with HPIS point of view, the whole transient can be divided into three main p

(i) the forced circulation period,
(ii) the two-phase natural circulation period,
(iii) the reflux condensation period.

During the first phase, after the opening of the break device, the MPa within 32 seconds, triggering both SG isolation and core powe is activated causing an upper limit to the increase in secondary p and at 74 seconds HPIS starts to inject water into the primary sys ends the forced circulation phase, and two-phase natural circulatio natural circulation stops and heat exchange with the secondary occurring in the steam generator U-tubes.

An important feature of the test is the liquid mass distribution insi flow paths in the vessel and by heat transfer across steam gene condensation periods. Since HPIS is sufficient to avoid core uncove

ISP 20: The considered transient in Doel plant is the steam longitudinal crack of 7 cm long located in the ascending leg of t plant in 1979 and constituted the first (and, so far, the unique) s 3). At the moment when the event occurred, the reactor was subcı heaters on. In the secondary side, the steam lines were both isc available. The main feed water pumps were not operational and v means of a letdown system. The auxiliary feed water pumps wer below the safety margins during the whole transient.

Figure 3: ISP-20 (Doel-2): registered data tre

The condensation induced by the pressurizer spray and in the secc interface is the relevant phenomena to be predicted by codes. H trends of the main quantities as well as the time of actuation of and capabilities of plant instrumentation and recording systems.

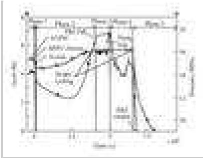
ISP 22: The test in the SPES facility consists of a loss of feed wat in one of the three loops of the facility. The transient evolves throu

(i) The accident beginning to scram: due to the loss of feed steam generator. As the low level set point is achieved, the sc the main steam isolation valves to close.
(ii) Scram to pressurizer PORV opening: after scram a qu consequence of temperature decrease. The steam generators rises continuously, causing primary system pressurization up to
(iii) Pressurizer PORV opening to pumps trip: while the pr approaching the saturation value, the pumps are switched off set point value.
(iv) Pumps trip to emergency feed water activation: due to t heat up occurs and the emergency feed water activation sign the high rod surface temperature set point.
(v) Emergency feed water activation to the end of the trar quick repressurization in the affected steam generator and re the secondary sides, with a consequent big decrease of prima in the affected steam generator increases steadily until the init

The following main features of the test can be pointed out.

(i) The pressure control of the primary system by the pre depletion cause rod surface temperature excursion roughly two
(ii) The actuation of emergency feed water in one loop leac draining, core quench, and brings the facility to safe sh accumulators actuation.

Figure 4: ISP-22 (SPES): experimental trends



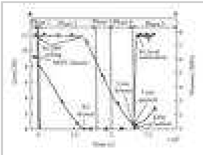


Figure 5: ISP-22 (SPES): experimental trends

ISP 26: The experiment in the LSTF test facility is originated by pressurizer, the HPIS is not available (Figure 6). Following the br scram occurred at 9 seconds. The core was temporarily uncovered after break opening. The reason for this was a core level depres condensation at the top of U-tubes and consequent liquid holdup i about 140 seconds, loop seal clearing occurred and caused a tem clearing, the break flow changed from low quality to high quality t loop was accelerated. By about 180 seconds after the break, tl generator secondary side pressure. Thereafter, the steam genera removal from the primary system occurred through the discharge clearing occurred before the reversal in primary and secondary pr 420 seconds due to vessel inventory boiloff; the heater rods in the about 80 K. The core was covered with two-phase mixture again injection. The peak cladding temperature in the test was approxin uncovery just before the loop seal clearing.

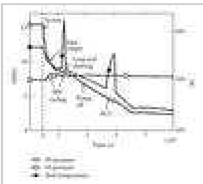


Figure 6: ISP-26 (ROSA-IV): experimental tre rod surface temperature.

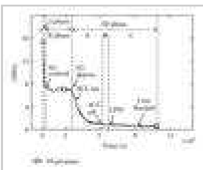


Figure 7: ISP 27 (BETHSY): experimental tren

The occurrence of two dry out and quench conditions constitute distribution in the loop and the heat transfer with secondary side assessment.

ISP 27: The test in BETHSY facility is an SBLOCA with the break with the pressurizer (Figure 7); HPIS is not available. Three differe

(i) subcooled blowdown;
(ii) mass depletion in primary side;
(iii) ultimate procedure.

Subcooled Blowdown

Following the break opening the primary pressure falls down and s safety injection signal (SI) occurs at 11.9 MPa. Following SI signa Before SI, secondary side pressure is controlled through the spra when turbine bypass occurs the pressure threshold becomes 7. seconds after SI signal, and pump coast down initiates 300 secc pressurizer and surge line empty leading to the relatively fast c period owing to the diminution of the heat transfer from prim secondary side starts to decrease.

Mass Depletion

The second phase is characterized by mass depletion and almost (saturation values). Oscillations in break flowrate in the first perioc the broken loop. Later on, with pumps at rest, once the upper hea cold leg, mostly steam flows at the break (stratified conditions w elevation of the exit nozzle axis). Loop seal clearing is recognizec stops with the occurrence of the first core uncovery. Secondary s this period. At the end of this phase, a second core uncovery occu procedure when the core maximum clad temperature reaches 723

The Ultimate Procedure

This phase of the test consists in fully opening the dump valves actuation; three different parts can be distinguished during the las part A, starting with the ultimate procedure initiation and ending v the U-tubes induces liquid fall back to the core, which is cooled f clad temperature to turn around and the core to be rewetted. Part isolation up to LPIS actuation. A continuous mass depletion of pr phase. No dry out situation occurs in this period during which the set point for LPIS actuation. Very early during part C, LPIS flowr recover the primary coolant system. In this period filling up the direct contact condensation between the cold liquid injected by LPI

7. The Results of Some Statistical Analysis for Smal

In the framework of the ISP activity evaluation, interesting inf considering the number of participants to the ISP, including cou thermal-hydraulic system codes. The main goals of the effort are activity from the international scientific community, and to deriv organisations in the use of large thermal-hydraulic system codes.

A wide database is available for making statistical evaluations; this by CSNI and in the individual ISP participants written contributior ISP workshops. A comprehensive analysis would require establish for example,

(i) computers have strongly evolved lowering the needed c cases, the calculation time increases just because transients ta
(ii) codes having sophisticated capabilities of noding a sp component in CATHARE) may need less overall number of node
once an acceptable convergence is reached from a num

(iii) once an acceptable convergence is reached from a num steps might not lead to any benefit; calculation time may b reducing the interaction number and meshing size.

However, a number of quantities could be used to characterize example, [16]. Following a discussion among the participating wor data (e.g., numbers of used meshes or nodes) averaged on the even misleading considering the present situation. This is origi including the different levels of qualification of the scientists direct purposes for organisations in participating in an ISP. As an exa number of input deck nodes for the different participants should n nodalization itself.

The lack, in the ISP documents of an exhaustive description of cal the time needed for the calculation of ISP exercises, as a paramete

Keeping in mind the above, the following quantities were selected t

(i) kind and number of participants to the ISP,
(ii) thermal-hydraulic codes used for the ISP calculation.

In relation to the first item, it seemed interesting to correlate th adopted codes used, considering the total number of participations

The second item gives an idea of the differences in the use of ea the analysis might not be indicative of the actual number of use context should be gathered by specific collaborative programmes Assessment and Maintenance Program (CAMP) or specific "ins International Conference.

Specific parameters to characterize the two items identified abov overall impact of ISP activity in the scientific community are

(1) number of participants to the specific ISP,
(2) participants per ISP,
(3) number of countries per ISP,
(4) participants per code per ISP,
(5) codes used per ISP.

ISP phases (e.g., pre- and posttest) are considered in Tables 6, 7 are given in these tables. As already mentioned, further informa number of parameters, can be found in [4, 16]. It is to be not participated in the small break LOCA ISP exercises. These are centres, universities, licensing authorities, industry, utility, and oth

Table 6: Participants per code per ISP.

Table 7: Countries, Participants, and Codes us

Table 8: Calculations per code groups per ISP

Detailed statistical data and analysis are included in [4]; in this p
the statistical data are given as follows.

(i) A large number of codes have been used in the differer
RELAP family of codes specifically from most of universities anc
(ii) A number of participants still use first generation (e.g., R
(iii) The number of participants increased after ISP 20 essen
the ISP activity was open for the non-OECD countries. The pc
information about Western countries safety methodologies. A
the scientists participating to the ISP for the first time, makir
the discussions about the ISP itself.
(iv) The use of well established or "frozen" versions of
assessment of the concerned code version against a full transie
(v) Fourty six organisations took part in the small break LO
to more than five of the considered ISP cases.
(vi) Of the above organisations, almost 82% belong to the r
institutes and 28% universities).

8. Some Lessons Learned from the Small Break Loc

The contents of this section are based on the answers received
members of TG-THSB who were involved in the analysis of most c
included in each of the ISP final report (CSNI reports, [5] to [1
which took place during the meeting in Pisa University in 1995.

As mentioned in Section 7, eighteen different codes were used by t
here to produce a detailed analysis of calculational performance
synthetic approach, to derive the main outcomes from the five ISF
items identified in the questionnaire:

(i) code deficiencies and capabilities,
(ii) progress in the code capabilities,
(iii) possibility of scaling,
(iv) other comments.

It should be mentioned that from ISP 18 to ISP 27, more and
transients which were dealt within the ISP exercises, such as c
secondary side voiding and filling, low pressure two phase flc
involvement of various phenomena during an ISP exercise must l
well as code users. Furthermore, increasing overall complexity a
calculated, can be noted during the process of going from the earli

8.1. Code Deficiencies and Capabilities

The code user is clearly the best judge of the performance of his c
of the quality assurance used when setting up the nodaliz
experimentalists play a major role in the quality of the results, this
a general, but not in depth evaluation of submitted results, two ste

list of relevant thermal-hydraulic phenomena in each t

(a) list of relevant thermal-hydraulic phenomena in each t
looking at the facilities suitability;
(b) identification of phenomena which were not well predicte

The quality of experimental data also had a role in selecting co which were identified, is provided in Table 9. As code deficie phenomenon is not predicted to occur in the calculation, or the p quantity $|Y_c - Y_E|/|Y_E|$ was larger than 0.20 (see also [9]). In th representing the assigned phenomenon and the deviation of calcul

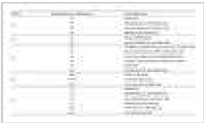


Table 9: General code deficiencies for the con

It can be seen from Table 9 that thirteen main code deficiencies different ISPs. A comprehensive and systematic qualitative or quar beyond the scope of the present paper. In this respect, some exar ISPs22, 26, and 27, respectively. Slightly different criteria are a (e.g., good, average, and poor) or a quantitative evaluation (e.g fourier transform- (FFT-) based method). For this type of evaluatic the mentioned documents. Additional notes on selected items are p

Let us first deal with the break flowrate problem (item 1) in Table many participants have experienced wrong predictions of this (sometimes large) from the actual transient. Although a very accu safety studies, where a stated range of break flowrate may be reasonably predict two-phase critical flowrates versus leak geom when the efficiency of operator actions (use of discharge devices ISPs, various levels of agreement on the break flowrate predicti correlated with the resources invested in this part of the work a however that some break models are still having difficulty to c conditions. In this area, an example of complex interaction betw interpretation of data provided by experimentalists is given in [18 about break discharge coefficients, performed during the ISP 27 p parameter upon the time scale shifting appearing in blind calcu previously adjusted by using the separate effect test experimenta mentioned study pointed out and also emphasized the need for agreement on integral test transients.

However, in general, break flow can be largely influenced by the u to the mass distribution in the entire system and to the overall break flowrate might introduce a compensation of errors and, conclusions. This also results in excluding to provide the ISP complicated geometries (such as valves), geometry effects on bre performance of the valves must be characterized and supplied as i

Another key parameter in these considered ISPs is the coolant mas 9, relevant to ISPs 18, 22, and 27), which is strongly related to th shear stresses, counter-current flow limitations, transitions betwe mass distribution. The need for a better prediction of this d generation ("advanced") two-phase thermal-hydraulic codes. predict the physical phenomena involved during the different trar

loop seal clearing, interfacial transport in core, and steam ger
revealed during the first of the considered ISPs and, concerning vc
still appeared unresolved in ISP 27 (see Table 9).

Additional specific comments are connected with the thermal cou
and secondary sides. This is a consequence of both the scaling r
procedures applied; this has been a subject of discussion during m
to different reasons in accounting for the fluid structure and the
inadequate consideration of heat losses, may have a role in vari
have demonstrated their ability to qualitatively describe these ph
that a sufficient amount of care and work had been spent to co
conditions.

In ISPs 26 and 27 discrepancies remain in predicting core heatup
Similarly "hot wall delay" effect in steam generators downcom
examples raised questions about the relevant heat transfer models

At last, some specific aspects specifics for one or two ISPs, such a
and low pressure refilling of the primary coolant system (ISP 27)
most of the codes.

From the point of view of the code capabilities, it must be indi
relevant phenomena even in the case when complex scenarios a
supported by quantitative evaluations, that is, quantification of
trends, in the cases of ISP 22 and ISP 27 (see also below).

However, looking generally to a single ISP, a wide range of results
versions. This emphasizes the role of the user in setting up the
boundary conditions supplied by the experimentalists. In conclusi
(see also below) the user effect may overshadow the reasons for
identify code capabilities

8.2. Identification of Progress in Code Capabilities

Firstly, it must be emphasized that one of the reasons why prog
isolate phenomena in an integral test. Owing to this fact, it is als
single code, since there is also no clear feedback between the
mentioned. In fact, ISPs have been proved more useful to prov
hydraulic codes, especially when posttest calculations or parame
deficiencies or failures. In this case, returning to the use of more
necessary to modify or extend the individual physical models
capabilities. The direct contact condensation, or stratification a
constitute an example of this.

Progress was also observed in using parallel channel simulation in
with the codes used, which are basically one dimensional. One of t
the area of users guidelines. Thanks to the large number of part
different nodalizations and option choices, the ISP pre- and postte
so called "user effect."

The small break LOCA ISPs provided a useful information basis, n
capability from one ISP to the other, but also for new code users t
meeting more experienced people in the frame of ISPs.

8.3. Possibility of Scaling

Although the considered five ISPs address the problem of scaling, very similar to that observed in the facilities which are properly facilities addressing the same thermal-hydraulic phenomenon, or b commonly reached conclusion is that small break ISPs alone are n counterpart tests performed making reference to the same scena different facilities, are much more valuable for this task [17, 19, 20

However, it is considered interesting to bring to the attention he was made in preparing CSNI report on "lessons learned from OEC

Two items are identified to judge the possibility of using the small

(A) Realism of involved physical phenomena as far as plant is
(B) Possibility to assess the code in different scaled facilit whether the small break LOCA ISP scenario can be found in dif

The analysis of each small break LOCA ISP related to the above tw

(i) *ISP 18*, item (A): test scenario expected to be similar in t
(ii) *ISP 18*, item (B): limited suitability because the test scen
(iii) *ISP 20*, item (A): this is a plant scenario.
(iv) *ISP 20*, item (B): the same scenario has been considered
(v) *ISP 22*, item (A): qualitatively, phenomena expected to b
(vi) *ISP 22*, item (B): test suitable for scaling because the sa
(vii) *ISP 26*, item (A): plant scenario expected to be the same
(viii) *ISP 26*, item (B): test suitable for scaling because the co
(ix) *ISP 27*, item (A): plant overall scenario expected to be th
(x) *ISP 27*, item (B): difficult to assess the code scaling ca available from other facilities.

As a result of the above, ISP 22 and ISP 26 related experiments a Even though it is a plant, ISP 20 mostly suffers of limitations due plant, both in relation to plant hardware and data recording, as alr

8.4. Other Comments

An additional outcome from the small break LOCA ISP activity in th of works about quantitative accuracy evaluation of codes. The res been used to check some of these methods and proved very useful

Another lesson from these small break LOCA ISPs concerns the e calculations on various facilities and transients, improving th weaknesses. Opening this activity to Eastern countries (since ISP small countries to have access to relevant experimental data, and codes and nuclear reactor safety.

A further lesson from small break LOCA ISPs concerns the ident Different code users utilizing the same code version and getting th (ISP host organisation) produce quite different results especially "open" standard problems. ISP 25 (not included in the present basis for the influence of the user on the results of calculations (found that, potentially, user effects can be very important and (same conclusion as in Section 8.1).

9. Conclusions

The ISPs are part of an important ongoing programme promoted b
among the other things, the possibility to disseminate the safe
scientists from different countries of the world, in a relevant are
activity gives a real challenge to all participants to analyze an ex
activity and compare the own calculation results with other results
all codes, which are used for comparing with the other codes.

The present work focuses on a limited part of the entire progran
phenomenon typical of small break LOCAs in PWRs. Four different
transient are involved. The considered set of standard problems re
area to the concerns raised by the TMI-2 accident and have been
been made available; definitely, the discussed ISPs and the advan
elements for ensuring reliability in safety evaluations in the are
transients like large break LOCA) potentially affected by operator a

In the frame of the presented activity, the involved experimen
characterized adopting the list of twenty two phenomena propose
for integral test facilities. This led to establishing qualitative simil
demonstrated that the latest small break LOCA ISPs, which were p
broader ranges of phenomena relevant to nuclear reactor thermal-

Whatever is the kind of ISP, "blind," "open," "double blind,"
agreement between code results and experimental data, depends
code physical models, to user experience, to nodalization details
supplied by the experimentalists, integration of this information int
finalized conclusions regarding the submitted calculations cannot
code users and the experimentalists; on the other hand, this is the
as a summary of each ISP, they are listed here as references.

Considering the above, the conclusions reached are of a quite gene
the different ISPs, as well as to small break LOCA related ISPs.

It was noted that large numbers of countries (more than 20) and
one small break LOCA ISP: these essentially include all countries
exception strictly connected with political reasons can be observe
all the considered ISPs and many organisations took part in on
number of code users increased and among these users, there we
carefully when deriving conclusions from the ISP activities. Assumi
of the participants since the time of the ISP 18 (first of the c
evaluations done in the frame of Section 7 and [4], lead to the follo

(a) The objectives in the participation to the ISP changed
development at the beginning and mostly focused toward use
for codes that did not reach an adequate maturity at the begin
(b) Notwithstanding the large effort necessary to organize
experience gained by a single organisation or by a single grou
not transferable or at least has not been transferred. This is
where the participant organisation or the group of scientists di
experience. This concerns code developers, experimentalists
problem common to the whole area of system thermal-hydraul

(c) The ISPs got more demanding with the time. There was example, the ISP 27 (BETHSY) could be calculated only with v calculated at all) at the time period when the ISP 18 (LOBI) wa

A list of thirteen deficiencies coming from the considered ISPs ar identified as in Section 8.1. This is not an exhaustive list, but However, it must be observed that very slow or almost no progre decade.

An additional aspect that should be brought to the attention is th assessment programme that, historically, has been the objective Program of USNRC (ICAP), Code Assessment and Maintenance P des Utilisateurs du CATHARE (CUC), and so forth or of nationa prevented a direct improvement of codes based on the results o detected in the frame of ISPs, owing to the relevance of the ISPs t code developers.

Furthermore, inadequacy or lack of direct feedback from the resu cases the consequence of the need to fix time frames and c "optimized" results with an assigned code version. For some p code versions also put obstacles as far as that feedback is conc achieving some user qualification, also contributed to the above co

Although a detailed evaluation/judgment of each ISP activity is framework, it seemed worthwhile to add few specific conclusions a

(i) A large mismatch may exist between the huge effort from the h one side, and the final result of the exercise.

(ii) Incomplete or even misleading information supplied by the complexities of the general code assessment problem and could conclusions.

(iii) In some cases, participants underestimated the effort necess consideration of initial and boundary conditions; this constitutes conclusions of the activities.

(iv) Especially, as a consequence of the above, quite vague form the ISP reports.

(v) A large range of results obtained by participants using the san uncertainty in selection of input parameters and uncertainties of c [11]).

9.1. Recommendations

General recommendations coming from the performed activity aspects connected with small break LOCA ISPs.

(i) The participation into ISP activities of non-OECD countries sh countries not having the capabilities for wide national research pro

(ii) Notwithstanding obvious drawbacks (e.g., lack of suitable instr

ISP based on an actual plant transient, if any, is highly recommenc

(iii) A better characterization of the experiments of ISPs, also in vi could be based on the 67 phenomena identified for the CSNI s available in mid 90 s [22, 23], future ISPs should directly conside

(iv) The interaction between ISP host/proposing organisation and far as the test selection is concerned, but could be improved espe for defining the impact of these in the thermal-hydraulic and nucle

(v) The inadequacy of a direct feedback (indirect feedback may e already been stressed. However, indirect feedback exists, as ISI phenomena such as phase separation at the junctions, stratificatio side heat transfer (ISP 27). Then, valuable information for in independent confirmatory analyses performed utilizing data from s a code inadequacy possibly identified when performing the analy confirmed and characterized by calculations based on SETF expe strongly recommended.

(vi) The list of code deficiencies given in the Section 8.1 could be effects tests facilities together with phenomena relevant in 2D/3D also be improved as far as possible, when a model inadequacy is fo

(vii) "Blind" types of ISPs should be preferred to "Open" type the ISP can be planned and reliable data can be supplied to the p opportunity to evaluate the user effect and better represents the c related calculations.

(viii) The experience acquired so far, the database available from c the cost of an ISP, suggests not to propose additional ISPs in the low pressure, scenarios involving complex accident managemer generation reactors are not part of this recommendation.

(ix) Some of the discussed ISPs have been utilized as sample ba quantification of the accuracy of calculation results. However, som host organisations, possibly in cooperation with CSNI, in the quantification of the accuracy. It could even be standard part of th

(x) In relation to user effect, in a long-term view, a part of the remove the need for the user to make ad hoc assumptions in orc lack of modelling; an example of this is modelling pressure drop at

(xi) In connection with the above, when applicable, the problem hydraulic codes when predicting scenarios relevant to nuclear p activities similar to the ISPs.

Finally, considering the effort expended in the preparation of ISI catalogued and stored so that it could be easily accessed for future

Nomenclature

A_b: Broken area size of steam generator tubes

A_{max}:	Maximum area size of steam generator tubes
ACC:	Accumulators
BAF:	Bottom of active fuel
BL:	Broken loop
CAMP:	Code Assessment and Application Programme of U.S. N
CEA:	Commissariat pour l'Energie Atomic
CEC:	Commission of European Community
CENG:	Centre d'Etudes Nucleaires Grenoble (present name: CE
CL:	Cold leg
CSNI:	Committee on the Safety of Nuclear Installations
CUC:	Cub des Utilisateur du CATHARE
D:	Diameter
ECC:	Emergency core cooling
EFW:	Emergency feed water
ENEA:	Ente nazionale energie alternative
HPIS:	High-pressure injection system
ICAP:	International Code Assessment Program of U.S. NRC (p
IL:	Intact loop
ISP:	International standard problem
JAERI:	Japan Atomic Energy Research Institute
JRC:	Joint European Centre
K_V:	Volume scaling factor
L:	Length
LOCA:	Loss-of-coolant accident
LOFW:	Loss of feed water
LPIS:	Low-pressure injection system
MSIV:	Main steam isolation valve
NEA:	Nuclear energy agency
OECD:	Organisation for Economical Cooperation and Developm
PORV:	Power operated relief valve
PRZ:	Pressurizer
PS:	Primary side
PSI:	Paul Scherrer Institut
PWG-2:	Principal working group on system behaviour
PWR:	Pressurized water reactor
RHR:	Residual heat removal
SBLOCA:	Small break LOCA
SG:	Steam generator
SGTR:	Steam generator tube rupture
SI:	Safety injection
SRV:	Safety relief valve
SS:	Secondary side
TAF:	Top of active fuel

TG-THSB: Task Group on Thermal-Hydraulic System Behaviour

TMI-2: Three Mile Island Unit 2

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learned from OECD/CSNI ISP on small break LOCA" [4].

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