Progress in Nuclear Energy 56 (2012) 79–90

Contents lists available at SciVerse ScienceDirect

Progress in Nuclear Energy

journal homepage: www.elsevier.com/locate/pnucene

Review

Preservation and use of integral system test facilities data: The experience of the LOBI data and the STRESA database

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ARTICLE INFO

Article history:
Received 21 July 2011
Received in revised form
6 December 2011
Accepted 13 December 2011

Keywords:
Thermal hydraulic experimental data preservation
Integral effect test facilities
System thermal hydraulic code assessment
LOBI facility and project
STRESA database

ABSTRACT

Experimental data recorded in Integral Effect Test Facilities (ITFs) are traditionally used in order to validate Best Estimate (BE) system codes and to investigate the behaviour of Nuclear Power Plants (NPP) under accident scenarios.

The extent to which the existing reactor safety experimental databases are preserved was well known and frequently debated and questioned in the nuclear community. The Joint Research Centre (JRC) of the European Commission (EC) has been deeply involved during years in several projects for experimental data production and experimental data preservation; in particular a big initiative was the LOBI ITF project.

In this context the STRESA (Storage of Thermal REactor Safety Analysis Data) web-based informatic platform was initially planned by JRC-Ispra with the main objective to disseminate documents and experimental data from large in-house JRC scientific projects, as LOBI ITF data, and later it was extensively used in order to provide a secure repository of ITF data exploiting modern computer information technologies for access and retrieve of the information.

The paper is focused in presenting one of the largest EC initiatives on the production of ITF data (the LOBI project), its use for system thermal hydraulic code assessment and its storage in the JRC STRESA node web platform (http://stresa.jrc.ec.europa.eu/stresa/). The objective of the paper is to further disseminate and promote the usage of the database containing these LOBI ITF data and to demonstrate long-term importance of well maintained ITF databases. At present the JRC STRESA database is maintained by JRC-Petten.

1. Introduction and background

During the last four decades a lot of effort has been dedicated to the evaluation of the Nuclear Power Plant (NPP) behaviour during accident conditions. Many complex best estimate system thermal hydraulic codes have been created, developed and maintained for simulating the transient behaviour of Light Water Reactors (LWR) and are used to demonstrate the NPPs safety. Predictions of the system codes are affected by uncertainty because of a number of reasons (Cherubini et al., 2011), consequently relevant experimental data simulating conditions expected in NPP, are needed to assess the validity of the computational models or system codes adopted in the nuclear reactor technology.

The consistent application of a thermal hydraulic system code includes code development and improvement, validation against experimental data, procedures for code use, code assessment, code application to NPP transients and proper evaluation of the uncertainties (Cherubini et al., 2011). In the area of code assessment or of confirmation of code capabilities validation against experimental data is essential, therefore Separate Effect Tests Facilities (SET) and Integral Effect Tests Facilities (ITF) have been used for already 30 years. ITFs are one of the main tools for the validation of best estimate thermal hydraulic system codes. The experimental data are also of great value when compared to the experiment scaled-conditions in a full NPP.

Huge efforts were done by the OECD/NEA Committee on Safety of Nuclear Installations (CSNI) from 1991 to 1997 in the construction of the SET Validation Matrix for thermal hydraulic system codes (Aksan et al., 1994) and ITF matrices for validation of realistic thermal hydraulic system computer codes (OECD-NEA-CSNI, 1987; Annunziato et al., 1996; NEA/CSNI/R(2001)4, 2001). They were also established by CSNI, focused mainly in PWRs, BWRs and one

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0149-1970/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.pnucene.2011.12.007

specific matrix for VVERs phenomena including also SET facilities. CSNI ITF validation matrix publication was issued in 1987 and updated in 1996.

The EC Euratom programme dedicated to research in the nuclear sector has been involved in reactor safety research since the inception of the JRCs in 1957. Much attention was given on providing reliable methodologies for a realistic estimate of reactors' safety margins, in both operational and accident conditions, through experimental and analytical investigations.

The extent to which the existing reactor safety experimental databases are preserved either in paper or in electronic format was well known and frequently debated and questioned in the nuclear community, considering also the capital investment required to establish and conduct such large-scale experimental programmes. This preservation is a mandatory requirement to support safety analysis and related training for future generations.

In the late 90s the Senior Group of Experts on Safety Research (SESAR), assembled by the OECD-NEA-CSNI reviewed the research being carried out in the field of nuclear reactor safety, identifying future requirements and priorities. In terms of nuclear reactor thermal hydraulic safety research, SESAR recommended cooperative research programmes in some of the test facilities still in operation and the preservation of acquired experimental databases.

One EC key initiative in the preservation of ITF data became reality with the CERTA Thematic Network (Addabbo et al., 2003). The objectives of the CERTA Thematic Network were intended at establishing a consolidated framework for the preservation of reactor safety thermal hydraulic databases acquired in European integral system test facilities and at providing data access/retrieval capabilities using modern web-based information technologies. CERTA assembled 10 major European institutional and industrial reactor safety research organizations that contributed to the network with their ITFs data.

Within this overall context the STRESA (Storage of Thermal REactor Safety Analysis Data) web-based informatic platform was developed. The native objectives were to store and disseminate experimental documents and data and analytical documents coming from large JRC scientific projects. The need to store data from large scale, unique and expensive JRC experimental programmes (LOBI, FARO, KROTOS, STORM) became mandatory. LOBI and FARO facilities produced data from totally 90 experiments with a global cost of 150 Meur.

The paper is focused in presenting one of the largest EC initiatives on the production of ITF data (The LOBI project), some past and present activities related to its use for system thermal hydraulic code assessment and its storage in the JRC STRESA web platform in order to further disseminate and promote the usage of the database containing these data.

2. The storage of thermal reactor safety analysis data (STRESA) database

The JRC-Ispra developed from the year 2000 the STRESA (Storage of Thermal REactor Safety Analysis Data) (Annunziato et al., 2001; Annunziato and Addabbo, 2005) web-based informatic platform in order to provide a secure repository of ITF data exploiting modern computer information technologies for access and retrieve of the information.

The STRESA database was planned with specific requirements that were very clear from the first versions of the tool:

1. In order to have full accessibility from any place, the database had to be accessed via Internet.
2. The accessibility of data had to be controlled whenever.
3. The authorization to access to specific documents or data is performed locally, by responsible or owner of data of a specific facility or test, not by an overall institution, external to data, except in case of specific authorizations.
4. The STRESA different nodes (databases) can be connected to a portal page from where to navigate forming a network.

The 3rd and 4th points were very important features of STRESA tool. The issue of releasing ITF data to external organizations has been a point discussed in several forums during the years. It is clear that the owner of ITF data wishes to control at any time this release of data to third parties, so it was an important issue to take into consideration when the design of STRESA was developed. These features resulted in a very attractive characteristic of the tool for many institutions to adopt STRESA nodes or to participate with their own nodes in a common network.

STRESA is a general-purpose database to store in several formats documents and data (from SET, ITF or NPP or calculations). The user can connect via internet to a server that will access to a database containing the data. The access to the data is dedicated to the server which is detached from the real data.

The main components of the STRESA database tool are:

1. The database files on the server: any format of file could be stored in the server computer disk, normally Microsoft Word, Excel or Adobe PDF files are used for the documents, Winzip or Winrar compressed files and text or binary files to store data, any kinds of video formats (AVI, MPEG…) for the films, etc. A particular way to store data (DAT format) is also available for the JRC facilities (FARO, KROTOS and LOBI) and called WinGraf mode, these data can be read and plotted with the WinGraf plot program developed by JRC-Ispra (Annunziato, 2000).
2. The Microsoft Office Access database: A Microsoft Access Database is organized in a group of tables that, for example, keep memory of the physical position on the disk of the electronic documents (drive and filename). The documents are accessed in hierarchical mode. The general structure for experimental facilities may be: Facilities → Tests → Documents/Data. A number of facilities where there were performed a number of tests or experiments. For each of these tests an arbitrary number of documents may have been stored.

   The subdivision adopted here is arbitrary: the Webmaster can decide a different one.

   The other main tables contained in the database are dealing with the list of users, the authorizations for releasing documents, the list of events, the groups of users, the type of documents, etc.
3. The HTML-ASP (Active Server Pages) pages: The user interface is produced by user-friendly accessible ASP web pages (in Visual Basic language), which allow the retrieval of the information, the plotting of the different steps through the hierarchical structure or the visualization of films or images.

2.1. Users and authorizations

New registered users receive a password via email (the user selected password + 4 characters selected randomly by the system) which allows them to enter in the STRESA database and see the list of documents or data stored inside the tests and facilities.

As the user is registered, his/her authorization level is 0, this means that the user can see the tests performed and list the available documentation, but cannot download any document with exception of public available documents, of level 0. Higher levels of authorization correspond to permissions to download specific documents/

data, all documents/data of a specific test, all documents/data of all tests of a specific facility. The maximum level of authorization, 4 corresponds to the Webmaster of the STRESA node. The system allows creating groups of users that have specific permission to single documents/data or all documents/data of a test or a facility.

The documents/data can have different levels of protection decided by the responsible/owner of the data when uploaded them on the server: level 0 is public documents/data, and higher levels 1, 2, 3 are restricted. Normally a user of level "*n*" is able to download documents of level "*n*" and below.

The usual procedure to access specific tests documents or data by the user is to make a request via the STRESA web page (that sends automatic email) to the responsible of the data,[1] indicated in the documents/data list. He/she should eventually be authorized and notified via email by the responsible of the data. Once the user gets this authorization, that normally does not take more than a couple of minutes, he/she is enabled to download, examine the requested data.

Theoretically, any subject or legal entity of the EU is entitled to access the data at the highest level of authorization. For non EU requesting sources eventually the appropriate EU services are consulted to determine whether data transfer is appropriate, before the download is authorized.

2.2. History of the STRESA, STRESA nodes, networks and facts

The STRESA web-based informatic platform was initially planned with the main objective to disseminate documents and experimental data from large in-house JRC scientific projects, mainly:

- LOBI thermal hydraulic experimental and analytical projects (1970–1994).
- FARO and KROTOS fuel melt-coolant interaction experimental and analytical projects (1991–2000).

The first version of STRESA node was on-line in the year 2000 with LOBI, FARO and KROTOS facilities data. STORM data was included later in the period 2007–2008.

A major characteristic of the STRESA database is that it can also be configured as a network database with a number of local databases. From the portal database, it is possible to make connection with other local STRESA nodes thus forming network of databases, which increases the potential and the power of this type of storing system. It has the peculiarity of the propagation of the authentication, so with one user and password from the portal it is possible to arrive to data of different local nodes. It is advisable, however not to register with same username and password for STRESA network portal and local STRESA node.

When STRESA is used forming a network, the portal of the network shows apparently the data information concentrated in a web page, in reality the resources are distributed over various STRESA nodes, respecting the rights (release authorization) of the data and/or documents. The authorization to download data is given by the responsible of the node database and not by the portal responsible.

It is possible to conceive more than one network based on the same or different nodes, either thematic or of any other purpose. As an example, the JRC STRESA node (http://stresa.jrc.ec.europa.eu/stresa/) contains LOBI, FARO, KROTOS and STORM data. The LOBI was part of the thermal hydraulic network STRESA-CERTA and FARO, KROTOS and STORM are part of the JRC STRESA-SARNET network regarding severe accidents data (Fig. 1).

In 2001 the EC FP5 Project Network CERTA was established and the STRESA-CERTA network developed by JRC-Ispra with several individual nodes connected, containing ITF data from several institutions: PSI-PANDA, Lappeenranta University of Technology-PACTEL, CEA-BETSHY, Studsvik-FIX-II, JRC-LOBI, University of Pisa-PIPERONE, Framatome-PKL and UPTF, AEKI-PMK, SIET-SPES.

In 2003 improvements of the STRESA database were performed (Pla and Annunziato, 2003) consisting in a user-friendly interface for uploading documents/data and objects and items, users and groups management.

In the recent years the JRC STRESA-SARNET network (Albiol et al., 2010; Van Dorsselaere, 2011) was initially developed inside the EC FP6 Project Network SARNET-1 and at present continues to be actively used in the EC FP6 Project Network SARNET-2. The JRC-Petten is at present in charge of its development and maintenance (http://stresa.jrc.ec.europa.eu/sarnet/).

Several individual nodes are connected to JRC STRESA-SARNET portal, containing severe accidents experimental data from several institutions, including the JRC STRESA node with FARO, KROTOS and STORM data developed by JRC-Ispra and maintained at present by JRC-Petten.

Other STRESA nodes and networks were developed along the years, and some of them are still active containing many experimental data; the list is not extensive: OECD-NEA Computer Code Validation Matrix (CCVM), University of Pisa node for PhD thesis, EC FP6 Project Network EURSAFE, OECD-NEA-SERENA project network, EREC (Elektrogorsk Russia, http://base.erec.ru/) (Davydov, 2009), FZK-ECOSTAR (http://nuklear-server.ka.fzk.de/stresa_ecostar//), Lappeenranta University of Technology (PACTEL ITF http://www.lut.fi/energy/et/yty/stresa) (Purhonen et al., 2006).

From all STRESA nodes the ones of JRC-Ispra (LOBI, FARO, KROTOS, STORM), EREC and Lappeenranta University of Technology have acquired the status of full completeness of experimental data, filling the database with all experimental data produced in their facilities.

STRESA system has been used not only for experimental data, but also as document repository, as for the SKM tool of the JRC Intranet, for activities related to project management.

Regarding STRESA facts, about 12,500 users have visited JRC STRESA node since 2000 till July 2011, this is about 1200 visitors per year. Since the JRC STRESA node was transferred from JRC-Ispra to JRC-Petten, September 2009, till July 2011, 24 new users have registered from all over the world. The total number of users registered in the JRC STRESA node is 215. This is not considering that users coming from the JRC STRESA-SARNET portal have also access to FARO, KROTOS and STORM data.

FARO and KROTOS data are the most selected and document requested, LOBI data had almost constant accesses and document retrieval rate since 2000, of about 120 documents per year. There has been a big increase in 2010 and half of 2011 where 284 and 165 documents, respectively, have been accessed.

3. The LOBI programme, the LOBI experimental data stored in the STRESA database and the LOBI code assessment

3.1. The LOBI thermal hydraulic safety research programme

The LOBI (LWR off-normal behaviour investigation) was a reactor thermal hydraulic safety research programme carried out by the JRC-Ispra site (Addabbo and Annunziato, 2000, 2006) from a joint undertaking between the EC and the former Bundesminister für Forschung und Technologie (BMFT) of Germany. Several industrial and institutional reactor safety research organizations from EU member countries joined the project.

[1] The responsible/owner of data can be a different person for different facilities, even for different tests inside the same facility. This person has not to be confused with the Webmaster of the node, who can be the same or different person.

Fig. 1. JRC STRESA-SARNET portal above (http://stresa.jrc.ec.europa.eu/sarnet/) and JRC STRESA node below (http://stresa.jrc.ec.europa.eu/stresa/) indicating FARO, KROTOS and STORM facilities.

The main objective was the investigation of basic phenomenologies governing the thermal hydraulic response of an ITF for a range of PWR operational and accident conditions; the programme was also aimed to the provision of an experimental database for the development and improvement of analytical models and assessment of system codes used in LWR safety analysis.

The LOBI ITF (Fig. 2) was a single plus a triple loop (simulated by one loop) full-power high-pressure integral system test facility representing an 1:712 scale (core power, volume and mass flow) model of a 4-loop, 1300 MWe PWR (Siemens-KWU type, Biblis B NPP reactor), built and located at the JRC-Ispra site.

The facility was operative in two different configurations: The LOBI MOD1 test facility configuration was designed mainly to meet the relevant requirements of Large and Medium Break Loss of Coolant Accidents (LB and MB LOCAs). A total of 28 tests were performed with this configuration during the period December 1979–June 1982. The LOBI MOD2 test facility configuration, operating since April 1984, represents an upgraded version designed to meet also all relevant requirements related mainly to the investigation of Small Break (SB) LOCAs and Special Transients. A total of 42 tests were performed in the period April 1984–June 1991.

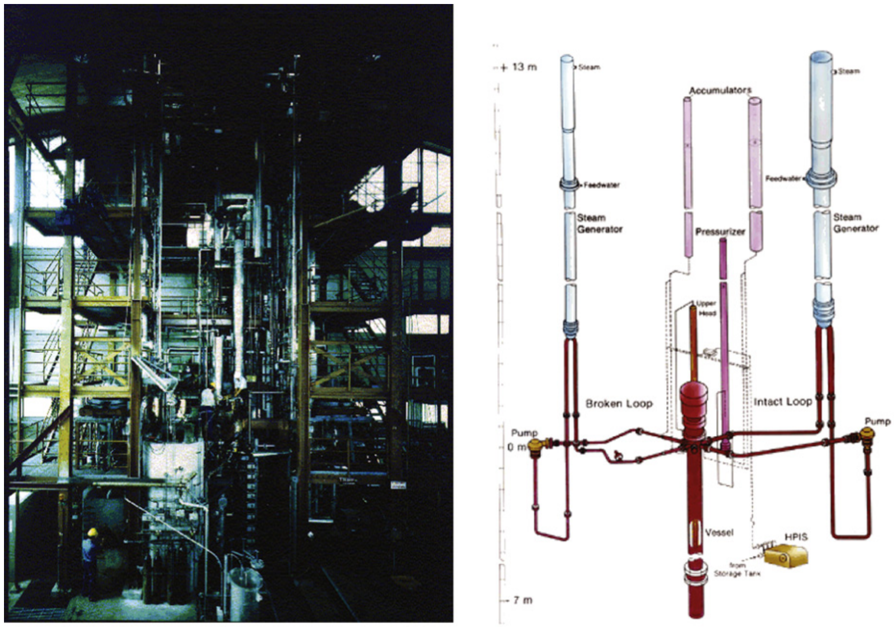
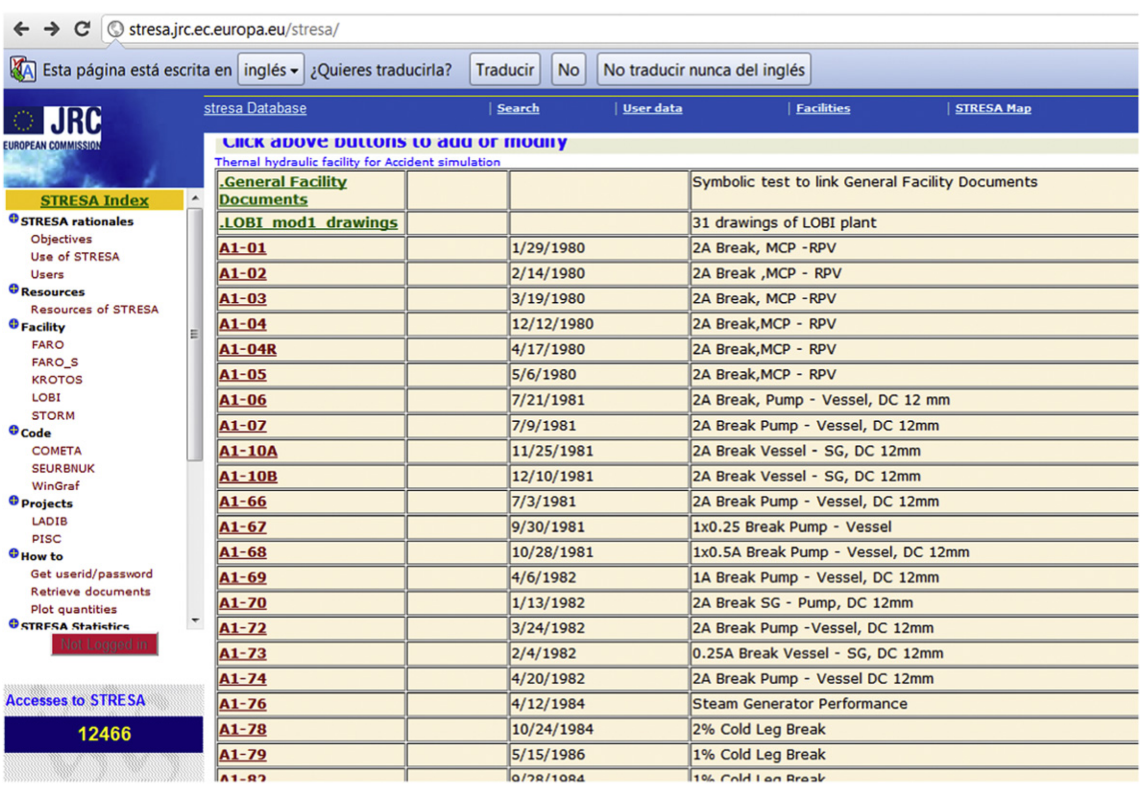


Fig. 2. LOBI MOD2 ITF photograph and schematic representation of the cooling system [from JRC STRESA database].

The LOBI ITF incorporated the essential features of a typical PWR primary and secondary cooling systems. It comprised the intact and the broken loop which represented respectively three loops and one loop of the reference PWR. Each loop contained a MCP and a SG. The simulated core consisted of an electrically heated rod bundle arranged in a square matrix inside the pressure vessel model. The primary cooling system operated at normal PWR conditions. Heat was removed from the primary loops by the secondary cooling system which contained a condenser and a cooler, the MFW pump, and the AFW system.

Hardware configuration, initial and boundary conditions were different depending on the test performed.

In the LOBI MOD2 ECCS water is injected into the primary loops through the accumulators, one in each loop, and the Low and High-



.General Facility Documents			Symbolic test to link General Facility Documents
.LOBI_mod1_drawings			31 drawings of LOBI plant
A1-01		1/29/1980	2A Break, MCP -RPV
A1-02		2/14/1980	2A Break ,MCP - RPV
A1-03		3/19/1980	2A Break, MCP -RPV
A1-04		12/12/1980	2A Break,MCP - RPV
A1-04R		4/17/1980	2A Break,MCP - RPV
A1-05		5/6/1980	2A Break,MCP - RPV
A1-06		7/21/1981	2A Break, Pump - Vessel, DC 12 mm
A1-07		7/9/1981	2A Break Pump - Vessel, DC 12mm
A1-10A		11/25/1981	2A Break Vessel - SG, DC 12mm
A1-10B		12/10/1981	2A Break Vessel - SG, DC 12mm
A1-66		7/3/1981	2A Break Pump - Vessel, DC 12mm
A1-67		9/30/1981	1x0.25 Break Pump - Vessel
A1-68		10/28/1981	1x0.5A Break Pump - Vessel, DC 12mm
A1-69		4/6/1982	1A Break Pump - Vessel, DC 12mm
A1-70		1/13/1982	2A Break SG - Pump, DC 12mm
A1-72		3/24/1982	2A Break Pump -Vessel, DC 12mm
A1-73		2/4/1982	0.25A Break Vessel - SG, DC 12mm
A1-74		4/20/1982	2A Break Pump - Vessel DC 12mm
A1-76		4/12/1984	Steam Generator Performance
A1-78		10/24/1984	2% Cold Leg Break
A1-79		5/15/1986	1% Cold Leg Break

Fig. 3. List of LOBI ITF Tests, as it appears in JRC STRESA database.

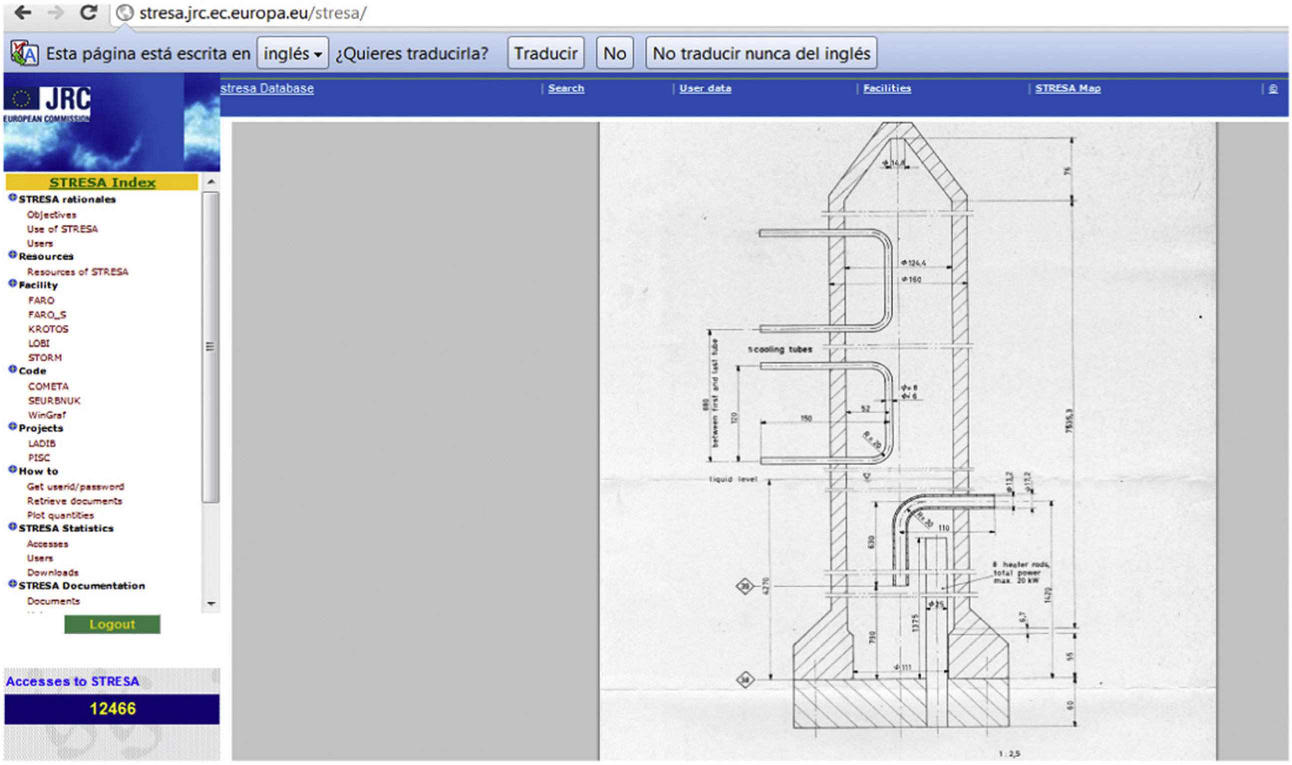


Fig. 4. Schematic drawing of the LOBI ITF pressurizer, as it appears in JRC STRESA database.

Pressure Injection System (LPIS, HPIS). Provisions are made for cold leg, hot leg or combined cold and hot leg ECCS injection in both primary loops and simulate some of the 4 pumps that exist in the reference plant, depending on the test. The accumulator of the intact loop has three times the volume and water capacity of that of the broken loop. In the LOBI MOD1 version of the test facility only the accumulator system was simulated. Additional safety injection systems consisted of the Volume Control System (VCS).

The measurement system comprised a total of about 470 measurement channels which allowed the measurement of all relevant thermal hydraulic quantities at the boundaries (inlet and outlet) of each major primary and secondary system loop components and within the reactor pressure vessel model and steam generators. A process control system allowed the simulation of time or pressure dependent parameters such as core decay heat release, main coolant pump hydraulic behaviour and safety injection flow rates. A fast running data acquisition system complemented the experimental installation.

Seventy experiments defined to represent safety cases in the relevant reactor were performed along the LOBI programme history. The financial investment required for each experiment was estimated with a cost of about 2 million euro. For each test the planned mandatory documentation produced was: Digital data set (measured experimental parameters), Experimental Data Report[2] (EDR) and Quick Look Report[3] (QLR). Test prediction reports (pre-tests) and Test comparison reports (post-tests) were produced optional as complementary documentation.

3.2. The LOBI ITF data as example of STRESA structure and storage of ITF data

Experimental data and documentation of all tests performed at the LOBI facility are available on-line through the JRC STRESA web database platform at the following address http://stresa.jrc.ec.europa.eu/stresa/. The JRC-Petten is at present in charge of JRC STRESA maintenance.

After selecting the LOBI facility the user has to provide username and password, the list of all seventy tests performed in the LOBI MOD1 and MOD2 facility appears (Fig. 3). Two sections correspond also to LOBI files containing general documents and drawings (Fig. 4).

Table 1 presents a summary or schematic description of the LOBI ITF seventy experiments.

By clicking in one test the list of documents/data produced is shown (Fig. 5); in this case it is shown for Test BL-30, a 5% break on the cold leg: The Quick Look Report (QLR) (Annunziato, 1990) and the Experimental Data Report (EDR) (Sanders and Ohlmer, 1990), scanned from the original documents. Three files containing experimental data at different time frames can be downloaded in ASCII or binary (DAT for Wingraf plot) formats. The last file, the collapsed liquid level film (Fig. 6) is very useful when analyzing complex experimental sequences in which the water masses are moving within the test facility.

If the user has enough authorization or the documents are public he/she will be able to see the documents/data and/or download them.

Otherwise the user has to make an on-line request of data to the data responsible/owner, which name and organization appears in the button below the list of documents (Fig. 5). For all LOBI ITF data

[2] EDR reproduces information contained in the digital data set, presenting plots and overlays of all measured parameters. Test initial and boundary conditions, as well as information about test facility configuration and operating characteristics needed for the interpretation of the measured data, are presented.

[3] QLR contains a preliminary analysis of the test results, generally supported by a series of plots of key parameters characterizing the test facility thermal hydraulic response under the specified accident or transient conditions. This report also contains general information concerning test specification, a short description of test objectives and information on test facility configuration.

Table 1
Summary description of the LOBI ITF experiments.

Type of accident/transient	LOBI configuration	Test number[a]	Notes
SB LOCAS[b]	MOD2, MOD1	SD-SL-01, SD-SL-02, SD-SL-03, A1-83, A1-84, A1-88, A1-91, A2-81 (ISP 18), A1-82, A1-78, A1-85, BL-00, BL-02, A1-79, BL-01, BL-21, BL-12, BL-16, A1-93, A1-94, BL-30, BL-22, BL-34, BL-44, BL-06	• 10% breaks in CL and HL. • 6% breaks in CL. • 5% break in CL. • 4% break in CL. • 3% break in CL. • 2% breaks in CL. • 1% breaks in CL. • 0.4% breaks in CL. • 0.4% PZR break. • SGTR (0.4%). • CL, HL or combined ECCS injection in both primary loops. • Cooldown (100 K/h) actuation in some tests. • Different power imposed. • DC gap 50 or 12 mm. • With Accident Management Procedures
LB and MB LOCAS[c]	MOD1	A1-01, A1-02, A1-03, A1-04, A1-04R, A1-05, A1-06, A1-07, A1-10A, A1-10B, A1-66, A1-70, A1-72, A1-74, A2-59, A2-59R, A1-69, B-101, B-222, B-302, A1-68, A2-55, B-R1M, A1-67, A1-73	• 2A breaks: Between MCP and RPV (CL) and between RPV and SG (HL) and between MCP and SG. • 100% breaks: Between MCP and RPV (CL) and between RPV and SG (HL). • 50% breaks in CL. • 25% breaks in CL and HL. • CL, HL or combined ECCS injection in both primary loops. • Different power imposed. • DC gap 50 or 12 mm.
Other accidents/transients	MOD2	A2-77A, A1-92	Natural Circulation.
Other accidents/transients	MOD2	A1-76	SG Performance under primary forced circulation.
Other accidents/transients	MOD2	A2-90	SBO.
Other accidents/transients	MOD2	BT-00, BT-02, BT-03, BT-56, BT-15/16, BT-17	LOFWs.
Characterization tests	MOD2	BC-01, BC-02, BC-03, BC-04	SG secondary mass inventory determination, SG heat losses determination, Core bypass flow measurement.
Other accidents/transients	MOD2	BT-01, BT-12	SLBs: 10% with PTS and plant recovery procedure, 100% orifice limited.
Other accidents/transients	MOD2	A1-87, BT-04	Cooldown transients.
Other accidents/transients	MOD2	BT-06	Feed Line Break (10%).
Other accidents/transients	MOD2	BL-40	SGTR in Zorita NPP for emergency procedures.

[a] Some tests were defined by experts assembled by the BMFT contractual partner (A tests) in the LOBI A Working Group and/or by experts from EC member countries research organizations (B Tests) assembled in the LOBI B Working Group. “A” tests were specified to reproduce phenomenologies of specific interest to PWRs of Siemens-KWU design, the test cases of the “B” type were instead specified to represent conditions of general interest in reactor safety analysis.
[b] According to LOBI classification of small breaks.
[c] According to LOBI classification of large and medium breaks.

the responsible is researcher Alessandro Annunziato from JRC-Ispra, who was highly involved in the LOBI experimental and analytical programmes and who was the developer of the STRESA tool.

By clicking on the request of data button is enough to select the desired documents/data, explain the reason of request in the appropriate textbox and submit the request (Fig. 7). An automatic email is sent to the responsible of data with copy to the user. As mentioned in the part “Users and authorizations” of Section 2.1, if the user is authorized, he/she will be informed by email and the next time that he/she will enter the site a link will appear on the documents/data requested which means that it is possible to download these documents/data. The user will get a copy of the original file, which will remain in the server database.

3.3. International activities, relevant LOBI tests and use of LOBI data for code assessment

The international context in which the LOBI research Programme was carried out offered many EC research organizations good opportunity for close collaboration and discussions to exchange concerns and expertise among the participants contributing thus to the harmonization of national views on reactor safety related matters.

As mentioned in Section 3.1 the tests of the B matrix were allocated to these EC member countries through research organizations. The tests preparation was agreed within the LOBI Task Forces and Working Group on the B Programme and the national organization was taken the responsibility to collaborate with the LOBI staff in the detailed specification of the test profile providing also in-house resources and computational tools for the pre-test prediction. The main organizations involved were:

- Belgium: TRACTEBEL
- France: CEA, FRAMATOME, EdF
- Germany: BMFT, GRS, Siemens-KWU
- Italy: ENEA, University of Pisa
- Spain: CIEMAT, UNION FENOSA
- UK: NE (CEGB), AEA, NII.

When using system codes in reactor safety analysis they are generally validated against experimental data from scaled ITFs. For obvious economic and practical reasons is not possible to compare the predicted transient response with test data from the full-size NPP.

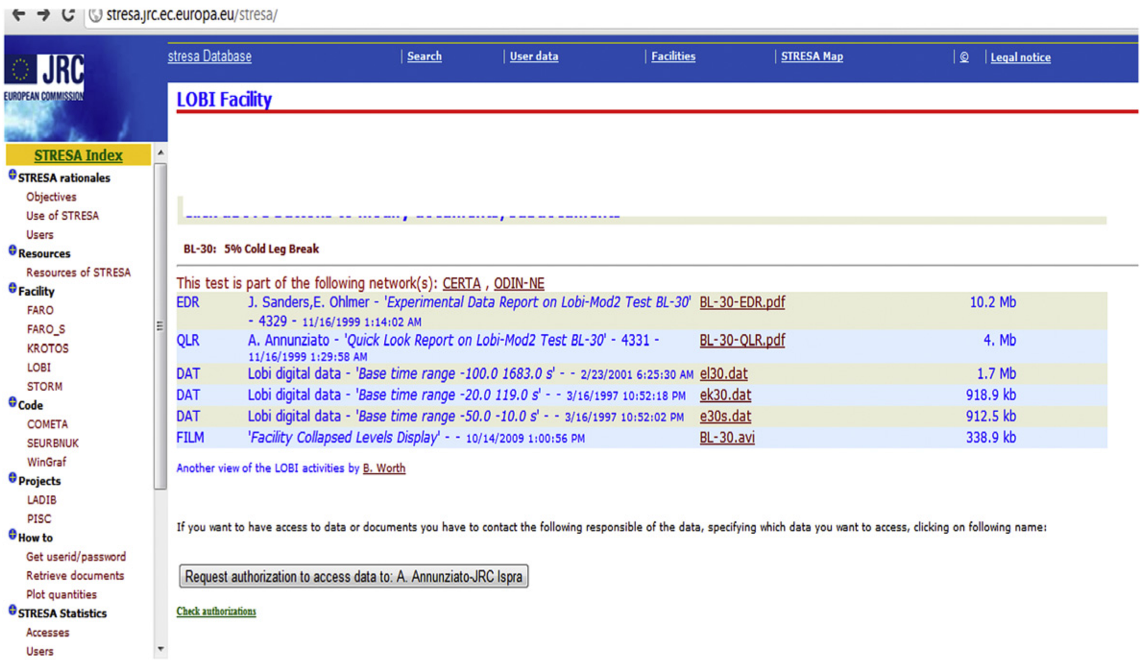


Fig. 5. List of documents/data of LOBI Test BL-30 and responsible of data, as it appears in JRC STRESA database.

When the predictive capabilities of a system code are scaled-up it is then desirable to assess the code against a set of data obtained from different ITF under similar initial and boundary conditions in order to observe the relevance of the geometrical scaling parameters.

Within this context, a number of LOBI MOD1 and MOD2 tests were carried out as counterpart to similar tests performed in other ITFs:

- LOBI test BR1M (25% CL break LOCA with accumulators in CL) was counterpart in Semiscale facility.
- LOBI tests A1-92 (Natural circulation characterization) and also A1-87 and A1-94 (Cooldown transient, one phase natural circulation under saturated conditions and 4% CL break) were counterpart in PKL facility (test AC.1 for A1-92 and test PKL-III for A1-87 and A-94)

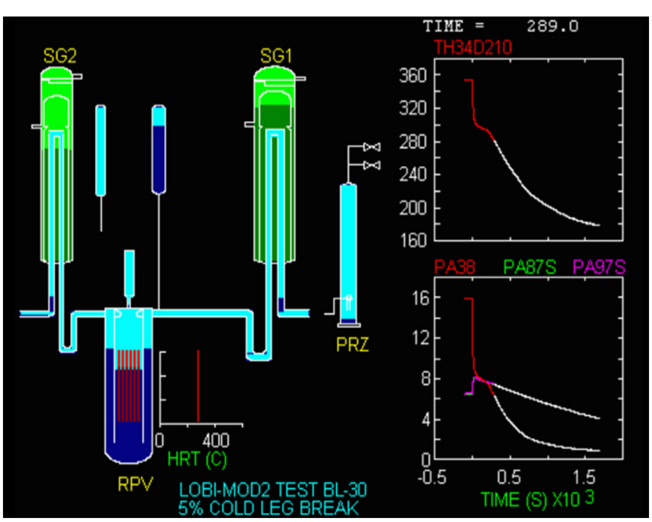


Fig. 6. LOBI Test BL-30 film of experiment collapsed levels display and primary and secondary pressures evolution [from JRC STRESA database].

- LOBI test BL-34 (6% CL Break LOCA, HPIS off, accumulators on and initial conditions scaled to low power (10%)) (D'Auria et al., 1999a) and LOBI test BL-44 (D'Auria et al., 1999b) (same conditions as BL-34 but full power) were counterpart in BETHSY, LSTF, PSB-VVER and SPES facilities tests.

Other LOBI tests were highly relevant for the understanding of thermal hydraulic phenomena and for system code assessment, mainly performed inside the duration of the LOBI programme, during the 80s and early 90s by the University of Pisa using RELAP/MOD2 and CATHARE1 V1.3/CATHARE2 V1.2 codes (Ambrosini et al., 1992)):

Test A2-77A was devoted to characterization of natural circulation and reflux condenser heat transport mechanisms at a primary system pressure of 90 bar and 70 bar. The characterization of instabilities in two-phase natural circulation and the evaluation of the user effect upon the code results were special goals achieved in the frame of the A2-77A analysis (D'Auria and Galassi, 1992; D'Auria and Frogheri, 2002).

Test A2-81 (1% CL break LOCA, HPIS in CL, accumulators off, secondary cooldown at 100 K/h, DC gap 12 mm) was the first test of the small break LOCA test series, and designated by OECD-NEA CSNI International Standard Problem 18 (ISP 18) (Stadke, 1987) with 27 participants organizations from 12 OECD member countries that provided blind prediction calculations with 9 different LWR system codes. The good nodalization of the flow rate multiplier at the break, the modelling of bypass flows and the number of nodes were key elements in the simulation of the mass distribution in the primary loop, which was an important feature in this test.

In Test A1-83 (10% CL break LOCA, HPIS in HL, accumulators in CL and HL, secondary cooldown at 100 K/h, DC gap 12 mm) the correct simulation of the bypass between the HL and the DC is of fundamental importance for the reproduction of the part of HPIS water flowing to the core. The correct simulation of the accumulator discharge was a shortcoming found in the CATHARE assessment.

Test A1-84 (10% HL break LOCA, HPIS in HL, accumulators in CL and HL, secondary cooldown at 100 K/h, DC gap 12 mm, it was counterpart to Test A1-83) was simulated with the CATHARE code

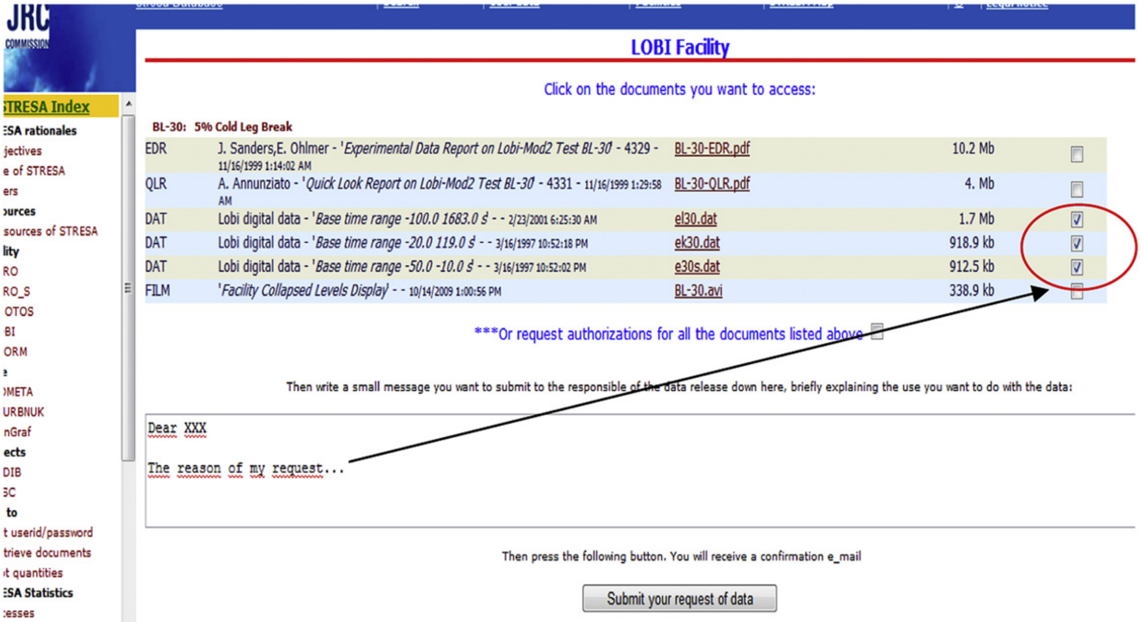


Fig. 7. List of documents/data request page, as it appears in JRC STRESA database.

showing residual mass and rod surface temperature well predicted; the correct simulation of the accumulator discharge was also a shortcoming and the modelling of the break flow was a source of uncertainty.

In Test BL-21 (Steam Generator Tube Rupture (0.4%). Intentional PCS depressurization through PORV and accumulators actuation as recovery procedure) calculated by RELAP code was shown that break mass flow is highly underpredicted, leading to different predictions in total primary mass and dryout. Reason for the discrepancy could be attributed to quality at the break and hot leg fluid stratification. With CATHARE code overprediction of break mass flow was observed.

Test A2-90 (Anticipated transient caused by loss of offsite and normal on-site electrical power with failure to SCRAM, diesels available) simulated (by RELAP code) boiloff of SG secondary system and SG refill and cooldown at 100 K/h. The code over-predicted depressurization rate was thought due to higher heat transfer through the U-tubes and errors in the PS mass inventory.

Test BT-00 (LOFW with primary Feed and Bleed procedure) simulated (by RELAP code) LOWF and SG boildown to 1 m, loss of AFW and SG dryout and long-term cooldown via primary Feed and Bleed. The code was not able to simulate the exact behaviour of the PZR valve characteristics. In the long term the PZR pressure was underestimated by the code, although the slope of the curve was correctly predicted.

Test BT-01 (10% SLB with PTS and plant recovery procedure through operator control of HPIS and PZR cooling) simulated by RELAP code showed results with underestimation of the heat

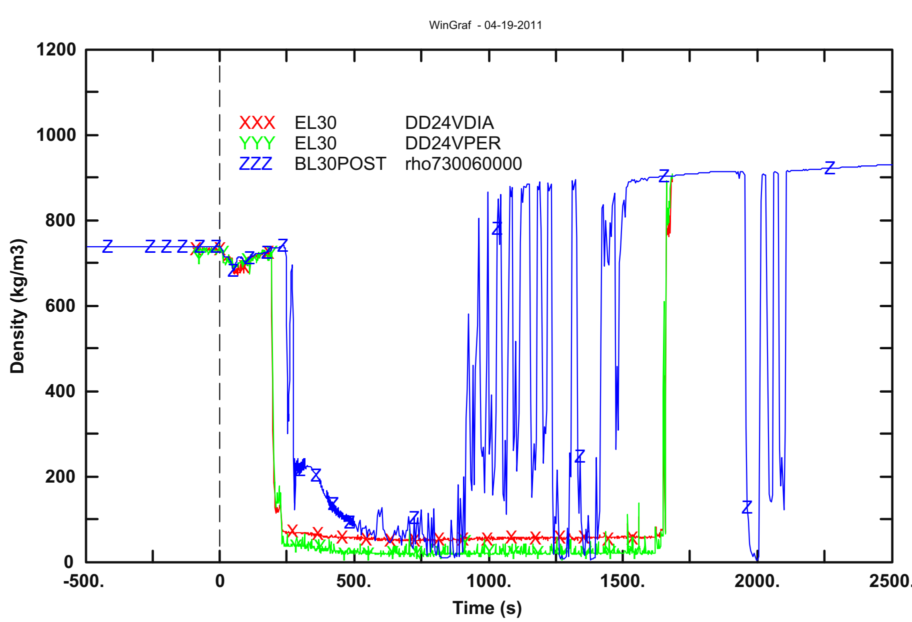


Fig. 8. Broken loop seal (pump inlet) density in LOBI Test BL-30 experimental (EL30) and RELAP Post-Test (BL-30POST).

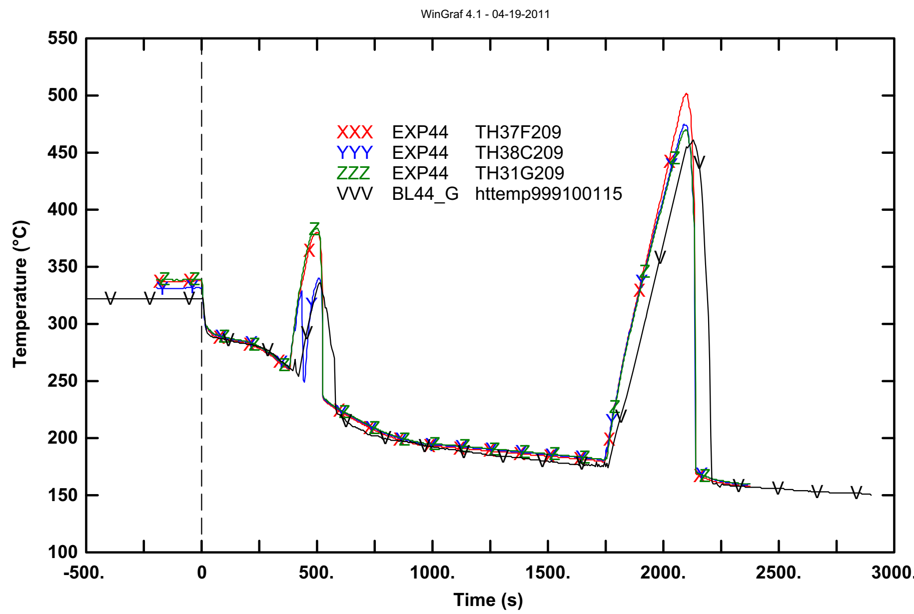


Fig. 9. Cladding temperature at core high level in LOBI Test BL-44 experimental (EXP44) and RELAP Post-Test (BL44_G).

transfer across the U-tubes. Qualitatively the transient was well predicted.

Test BT-03 (ATWS originated by LOFW with no HPIS available) simulated by RELAP code showed that in the calculation accumulators were capable of quenching the core few tens of seconds after their actuation. In the experiment did not occur and it was necessary to shut off electrical power to avoid damage. PS and SS pressure were correctly simulated. The discharge coefficients at valves and the coupling between PS and SS were critical issues in the simulation of the test.

In the recent years (last 6–7 years) several code validation activities were performed against LOBI experimental data in universities and research centres, this demonstrates once more the long-term importance of well maintained ITF databases like STRESA. These activities are related to conference or journal papers (Reventós et al., 2012; Pla et al., 2007a,b) and University (UPC, UNIPI) Nuclear Engineering Master Thesis (Berthon, 2005; Baltzer, 2007; Bailo Callejón, 2007; Fiori et al., 2009; Nacci, 2011; Matteoli, 2011; Lucas, 2011).

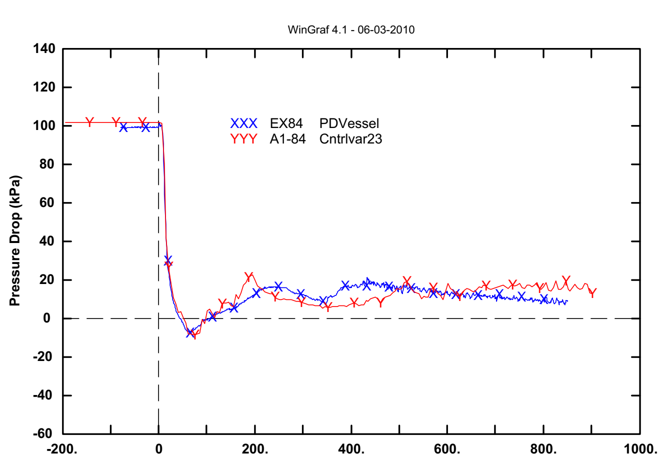


Fig. 10. Vessel pressure drop in LOBI Test A1-84 experimental (EX84) and RELAP Post-Test (A1-84).

Among them the most recent consistent post-test activities (Reventós et al., 2012; Nacci, 2011; Matteoli, 2011 were related to LOBI Tests BL-30, BL-34 and A1-84. The post-tests showed current good simulation capabilities of the codes (RELAP5 3.3):

For Test BL-30 (5% CL break LOCA, HPIS in CL, accumulators in CL, secondary cooldown at 100 K/h). Fig. 8 shows density at the pump inlet zone in the broken loop showing good agreement of the calculations with the experimental occurrence of the loop seals clearance. For Test BL-44 (6% CL break LOCA, no HPIS available, accumulators on at 40 bar, initial conditions at full power). Fig. 9 shows experimental and calculated data at high core level in the axial direction. Calculated rod surface temperature trends follow well the measured values, dryout situation are well predicted. For Test A1-84 (10% HL break LOCA, HPIS in HL, accumulators in CL and HL, secondary cooldown at 100 K/h). Fig. 10 shows the pressure drop along the vessel, from the inlet of the downcomer, to the outlet of the vessel (hot leg inlet). The trend is well reproduced by the code, demonstrating that the calibration of the loss coefficient in the primary loop, has been executed correctly.

To conclude the discussion about code assessment, it is worthwhile to mention that the correct simulation of the break mass flow, especially in the case of two-phase critical flow is an issue where code developers have put much effort in the last decades (Pla et al., 2007a). At present new models, in general, (Henry-Fauske) can predict this behaviour with somehow good accuracy.

Finally an important engineering activity (Fiori et al., 2011) performed by the San Piero a Grado Nuclear Research Group of the University of Pisa has been recently completed within the framework of the Argentinean utility NA.SA and the Atucha II NPP, in construction and licensing in this country. It deals with the development of an Engineering Handbook related to LOBI MOD2 based on drawings and data information and it is part of the RELAP code validation support documents to the Chapter 15 (Accident Analysis) of the Safety Analysis Report developed by the research group.

4. Conclusions

The LOBI ITF was a single plus a triple loop (simulated by one loop) full-power high-pressure integral system test facility representing an 1:712 scale (core power, volume and mass flow) model of a 4-loop, 1300 MWe PWR. Primary and secondary sides contain all the main active elements. It was located and operated at the EC JRC of Ispra, Italy.

The LOBI (LWR off-normal behaviour investigation) was a reactor thermal hydraulic safety research programme carried out by the EC JRC which main objectives were the investigation of basic phenomenologies governing the thermal hydraulic response of an ITF for a range of PWR operational and accident conditions and the development of an experimental database for the validation of analytical models and system codes used in LWR safety analysis.

In this framework the JRC-Ispra developed the STRESA (Storage of Thermal REactor Safety Analysis Data) web-based informatic platform in order to provide a secure repository of ITF data exploiting modern computer information technologies for access and retrieve of the information. The structure and the characteristics of the database were presented in the paper.

The paper presented the information about the stored ITF LOBI data in the JRC STRESA node database (http://stresa.jrc.ec.europa.eu/stresa/) in order to further disseminate and promote the usage of the database containing these data. At present the JRC STRESA node database is maintained by JRC-Petten.

The activities performed along the years and recently using LOBI ITF data for system code assessment demonstrate the long-term importance of well maintained ITF databases like STRESA. Access to reactor safety thermal hydraulic databases will be a continuing requirement to support the assessment/improvement of current system codes.

These activities are also crucial points in the maintaining and transferring human resources capabilities from senior to young generations in the area of nuclear safety, where industry, regulator, academia and research have to work together to avoid decrease or lack of skilled resources in the future decades.

Abbreviations

ATWS	anticipated transient without SCRAM
AFW	auxiliar feedwater of SGs
BE	best estimate
CL	cold leg
CSNI	committee on safety of nuclear installations
DC	downcomer
EC	European Commission
ECCS	emergency core cooling
EDR	experimental data report
EU	European Union
GRNSPG	San Piero a Grado Nuclear Research Group, University of Pisa
HL	hot leg
HPIS	high-pressure injection system
ITF	integral effect test facility
JRC	Joint Research Centre of the EC
LB LOCA	large break loss of coolant accident
LOBI	LWR off-normal behaviour investigations
LOFW	loss of FW
LOAF	loss of AFW
LPIS	low pressure injection system
LWR	light water reactor
MB LOCA	medium (intermediate) break loss of coolant accident
MCP	main coolant pump
MFW	main feedwater of SGs
NPP	nuclear power plant
OECD/NEA	Organization for Economic Co-operation and Development/Nuclear Energy Agency
PCS	primary coolant system
PS	primary system
PTS	pressurizer thermal shock
PWR	pressurized water reactor
PZR	pressurizer
QLR	quick look report
RPV	reactor pressure vessel
SB LOCA	small break loss of coolant accident
SBO	station blackout
SESAR	Senior Group of Experts on Safety Research
SET	separate effect test facility
SLB	steam line break
SG	steam generator
SGTR	steam generator tube rupture
SS	secondary system
STRESA	storage of thermal reactor safety analysis data
UNIPI	University of Pisa
UPC	Universitat Politècnica de Catalunya, Technical University of Catalonia

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