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NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

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BUBBLER CONDENSER RELATED RESEARCH WORK

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ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), Korea (12th December 1996) and the Slovak Republic (14th December 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 27 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The NEA Committee on the Safety of Nuclear Installations (CSNI) is an international committee made up of scientists and engineers. It was set up in 1973 to develop and co-ordinate the activities of the Nuclear Energy Agency concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international co-operation in nuclear safety amongst the OECD Member countries.

The CSNI constitutes a forum for the exchange of technical information and for collaboration between organisations which can contribute, from their respective backgrounds in research, development, engineering or regulation, to these activities and to the definition of its programme of work. It also reviews the state of knowledge on selected topics of nuclear safety technology and safety assessment, including operating experience. It initiates and conducts programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach international consensus in different projects and International Standard Problems, and assists in the feedback of the results to participating organisations. Full use is also made of traditional methods of co-operation, such as information exchanges, establishment of working groups and organisation of conferences and specialist meeting.

The greater part of CSNI's current programme of work is concerned with safety technology of water reactors. The principal areas covered are operating experience and the human factor, reactor coolant system behaviour, various aspects of reactor component integrity, the phenomenology of radioactive releases in reactor accidents and their confinement, containment performance, risk assessment and severe accidents. The Committee also studies the safety of the fuel cycle, conducts periodic surveys of reactor safety research programmes and operates an international mechanism for exchanging reports on nuclear power plant incidents.

In implementing its programme, CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health and NEA's Radioactive Waste Management Committee on matters of common interest.

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Note

For coherence with previous OECD documents, it has been decided to use in this report the expression "Bubbler Condenser", rather than "Bubble Condenser" used in other contexts, e.g. the BCEQ Project.

EXECUTIVE SUMMARY

Intensive discussions within the OECD Support Group on “VVER-440 Bubbler Condenser Containment Research Work” between 1991 and 1994 demonstrated the need for supplementary research work to achieve an adequate level of basic knowledge.

In 1994, the European Commission (EC) asked for a specific “VVER-440/213 Bubble Condenser Qualification Feasibility Study”, which was finished early in 1996, confirming the need for additional research in this field.

The Feasibility study formed the basis for the Bubble Condenser Experimental Qualification Project (BCEQ) with two separate experimental activities to be executed within the frame of the PHARE/TACIS 2.13/95 project of the European Commission.

A first activity served to study the thermal-hydraulic phenomena and the associated structure dynamic interactions. This part of the project was performed at EREC, in Elektrogorsk, Russia. The design of the test facility was based on the prototypical bubbler condenser configuration for the Hungarian ***Paks*** nuclear power plant.

A second activity addressed the structural integrity of certain components of the bubbler condenser steel structures under DBA-typical conditions. This part of the project was performed at VÚEZ, in Levice, Slovak Republic. The design of the components of this facility was based on the structural properties of the ***Dukovany*** and/or ***Bohunice*** nuclear power plants.

A third component of the BCEQ project was specified later asking for analytical studies, which should be supported by a number of small-scale separate effects tests to be performed at SVUSS, in Bechovice, Czech Republic.

The main experimental and analytical results of the BCEQ test campaigns have been presented and discussed within the frame of the 4th meeting of the Technical Advisory Committee to the BCEQ (Bubble Condenser Experimental Qualification) Project in Brussels in December 1999 and on occasion of the 11th OECD Support Group Meeting in Berlin in April 2000. The discussions had evidenced several contradictory points of view amongst the experts addressing interpretation and extrapolation of the obtained results.

Summarising the presented results and the subsequent discussions the following observations have been made with respect to the usefulness of the BCEQ project:

- Pending detailed analyses of the blowdown discharge rates generated during the three large break LOCA (Loss-of-Coolant Accident) tests at EREC, these tests may indicate that the maximum differential pressure of 30 kPa indeed covers the ultimate pressure loading cases.

- Substantial work would be needed to understand the reasons for observed but unexpected non-uniformities of local flow rates in the connecting corridor and water heat-up on the tray of the EREC test rig which is much smaller compared to the containment system with bubbler condenser of a full-size nuclear power plant (NPP) and to assess their importance for containment safety.

- Additional work is still necessary to reach a comprehensive understanding of the containment with bubbler condenser structures. In particular, the phenomena dominating small and intermediate break size LOCA situations remain to be addressed in additional testing. The probability of such scenarios will be larger than that of a large break LOCA. During a LOCA caused by small and/or intermediate size breaks as well as by a Main Steam Line Break (MSLB) the occurrence of flow conditions promoting the onset of oscillatory condensation and even chugging will be more likely and the duration of such situations under SBLOCA (Small-Break LOCA) conditions will be much longer.

- The results of the quasi-static structural tests performed at VÚEZ obviously are less difficult to interpret and extrapolate to a prototype NPP due to the chosen test rig concept and the applied testing procedures. The quasi-static nature of the structural tests performed in the frame of the VÚEZ activities in combination with the installation of original structures of the gap-cap systems and of confining walls with original material properties allows to conclude on similar stress/strain mechanics behaviour of the NPP bubbler condenser structures under equivalent loading conditions. The representativeness of the 30 kPa value for the maximum differential pressure and of the failure location to which the VÚEZ test rig has been subject remains to be definitively proven.

- With respect to the applicability of experimental data generated in the frame of the BCEQ Project, the Technical Safety Organisations (TSO) Group providing technical support to the regulatory authorities of the Beneficiaries will play an important role.

<u>*Based on these observations the OECD Support Group recommended*</u>

- to perform further post-test analyses of the results obtained so far

- to use post-test calculation results for the bubbler condenser design qualification, code validation and modelling improvements

- to perform tests simulating the main steam line break (MSLB), the medium and small break LOCA accidents in order to better understand non-uniformities

- to perform further bubbler condenser investigations for the ***Kola*** nuclear power plant,

with priorities to be assigned

- to post-test analyses of available experimental results

- to the investigations of non-uniformities in temperature and flow velocity distributions observed in the EREC tests

- to perform pre-test calculations for the remaining tests of the originally contracted EREC test matrix

– to primarily assess the aforementioned items of interpretation and extrapolation of the BCEQ results by a TSO project before a definitive safety assessment of the containment with bubbler condenser, also regarding related safety improvement actions should be released.

The BCEQ Consortium partly disagrees with the analysis and conclusions made in the attached report and the above recommendations.

The report has been endorsed by the NEA Committee on the Safety of Nuclear Installations for publication in the series of CSNI Reports at a meeting held in December 2000.

1. Introduction

VVER-440/213 Pressurised Water Reactors have a pressure suppression containment structure called a "Bubbler Condenser" (BC) tower which can reduce the design pressure of the entire containment following a design basis accident (DBA), such as a loss-of-coolant accident (LOCA). The bubbler condenser pressure suppression system provides reduction of the LOCA containment pressure by the expansion of the released steam to a large volume and condensation in a water pool. World-wide there are 14 nuclear power plants of the VVER-440/213 type operating in the Czech Republic, Hungary, the Slovak Republic, Russia and Ukraine. The thermodynamic principle of the bubbler condenser containment function is identical to the function of the containments of Western boiling water reactors with pressure suppression systems but the boundary conditions (construction and dimensions) are different. There was a strong interest in OECD Member countries to evaluate the analytical and experimental background available to design and license both containment systems.

Intensive discussions within the OECD Support Group on "VVER-440 Bubbler Condenser Containment Research Work" between 1991 and 1994 revealed the need for supplementary research work to achieve an adequate level of basic knowledge. This resulted in a proposal for a new multiple gap-cap system test rig and for the finalisation and utilisation of an unfinished test facility in Zugres (Ukraine). The main findings of the Support Group work have been summarised in a report on the status of the bubbler condenser system for VVER 440/213 reactors /KAR98/ as follows:

The earlier experimental database for the design of the bubbler condenser containment system was reviewed. Mainly, two experimental facilities, the so-called "Reduced Bubbler Condenser Model" and the "Enlarged Experimental Model" served to confirm early design decisions. The structure-dynamic properties of the chosen gap-cap systems and of the confining walls of these structures were not well known. No studies were performed at that time with respect to the interaction between oscillatory condensation and the structure-dynamic response of the gap-cap systems and its confining structures.

The OECD Support Group identified the need for a supplementary proposal for a multiple gap-cap system test rig. The Czech SVUSS Research Institute had elaborated a concept, which was based on the use of original bubbler condenser structural components of a nuclear power plant. Thirty-six gap-cap systems were to be tested simultaneously. This concept preserved the structural eigenfrequencies of the bubbler condenser elements to the largest possible extent. Experiments were to focus mainly on the response of the structures of the condenser elements to the oscillatory bubbler condensation process. Detailed discussions showed that thermal stratification within the bubbler condenser tower needs also to be studied. As a consequence, both concepts were combined into the so-called "Unified Bubbler Condenser Research Project" (UBCRP) avoiding to the largest extent any duplication of experimental works./BAL94/

The following phenomena were considered important to fully understand and assess the efficient function of the bubbler condenser containment system:

- *Dynamic loading of the gap-cap system by mass flow-induced differential pressures upon occurrence of a LOCA,*
- *oscillatory loading of the flat water pool trays by condensation phenomena,*
- *Water carry over into the air traps during the impulsive air transfer period,*
- *Possible limitations of the air flow from the bubbler condenser into the air traps in case of approaching sound velocities inside the check valves,*
- *Efficiency of the bubbler condenser tower in case of partial failure of the condensation trays or of single gap-cap systems (e.g. bypass formation).*

2. Interim developments

A report of status and research plans for the VVER-440/213 Bubbler Condenser Containment has been given on occasion of the OECD/NEA International Seminar on the Safety Research Needs for the Russian-Designed Reactors in Tokyo in July 1997. The main purpose of the International Seminar was to bring together experts in research works, to provide a hearing for progress of programmes sponsored by governments and OECD/NEA, and to review significant new technical information coming from these programmes.

Amongst a variety of technical conclusions drawn during the Seminar the importance and urgency to demonstrate the effectiveness of the confinement systems with bubbler condenser in accident conditions has been confirmed and strong support to get the experiments underway and completed was expressed /NEA97/.

The 10th meeting of the OECD Support Group was held in Budapest in October 1998 to discuss the progress in resolving identified bubbler condenser problems of interest. It heard summary reports on various national studies in connection with the bubbler condenser problems proceeding in Hungary (worst case studies for the behaviour of the BC in case of complete lack of water), the Slovak Republic (commissioning of the ***Mochovce*** Nuclear Power Plant), the Ukraine (studies concerning the possibility of reversed pressure differences during active and passive spray cooling periods) and Germany (activities in supporting application of codes like RALOC and DRASYS and interpretation of results in various countries).

It also took note of a project study to utilise the Bubbler Condenser System (BCS) installed in Unit 6 of the decommissioned Greifswald Nuclear Power Plant (Germany) for integral confirmatory testing.

The basic idea behind this concept was to provide confidence in the design and reliability of the bubbler condenser system comparable to Western BWR containments with pressure suppression systems. Interpretation and extrapolation of small-scale experimental results to real plants might eventually remain an issue. Experiments on an actual VVER unit could demonstrate the preservation of integrity of the VVER-440/213 containments under Design Basis Accident conditions.

In further evaluating these ideas SKODA had approached Energiewerke Nord (EWN), the present owner of the decommissioned Nuclear Power Plant Greifswald, to make Unit 6 available for tests of this kind. Unit 6 has never been put in nuclear operation and is not contaminated.

The main objectives of the SKODA testing concept were:

- the confirmative demonstration of the functionality and integrity of the bubbler condenser system under LOCA conditions

- full scale integral experiments complementing the expected results of the PHARE Project 2.13/95 with the aim to compensate remaining uncertainties in the extrapolation of small scale test results to actual nuclear power plants

- global verification of analytical simulation models under full scale conditions.

First estimations on the necessary funding were given. SKODA evaluated the technical preparation of the facility to require approximately 0.9 million euro. Execution of the entire project including analytical support and the interpretation and assessment of the results have been estimated to need 20 million euro.

Regarding possible sources of funding SKODA had in mind to address the owners of Nuclear Power Plants utilising a containment system with bubbler condenser and/or their potential Western twinning partners as well as the European Commission.

The SKODA concept has been extensively discussed by the OECD Support Group. Several issues were raised drawing specific attention, e.g. to

- the possible impact of the break location on the experiment
- the possibility to study also the effects of steam line breaks
- the repeatability of tests
- the possibility to study hydrogen mixing phenomena

Postponement of the project until termination of the PHARE Project 2.13/95 was advocated by several experts during the discussion.

Although an integral confirmatory test programme as proposed by SKODA would have offered the unique opportunity to directly demonstrate the preservation of integrity of bubbler condensers under LOCA conditions SKODA was not successful in raising the necessary funding and later on terminated the project.

3. The objectives of the Bubble Condenser Experimental Qualification Project (BCEQ)

In 1994 the European Commission (EC) asked for an additional “VVER-440/213 Bubble Condenser Qualification Feasibility Study”, which was finished early in 1996, confirming the need for additional research in this field. At the end, this study served as the basis for the “Terms of Reference” (TOR) of the European Commission funded bubbler condenser research programme.

The TOR specified two separate experimental activities to be executed within the frame of the TACIS/PHARE assistance programme of the European Commission.

A first programme would serve to study the thermal-hydraulic phenomena and the associated structure dynamic interactions on the basis of a prototypical bubbler condenser configuration for the Hungarian ***Paks*** nuclear power plant.

A second programme would address the structural integrity of certain components of the bubbler condenser steel structures under DBA-typical conditions. The design of the components was to be closely linked to the structural properties of the ***Dukovany*** and/or ***Bohunice*** nuclear power plants.

Complementing these two working programmes, a third component of the research project was specified later asking for analytical studies, which should be supported by a number of small-scale separate effects tests.

In 1997 the **Bubble Condenser Experimental Qualification Project (BCEQ)** was awarded to a Consortium consisting of Siemens/KWU (Project Manager), Electricité de France and Empresarios Agrupados.

The Electrogorsk Research and Engineering Center for Nuclear Power Plant Safety (EREC) near Moscow (Russia), the Power Equipment Research Institute (VÚEZ) in Levice (Slovak Republic) and SVUSS in Bechovice (Czech Republic) were selected as local Eastern subcontractors to perform considerable parts of the engineering work. The contracted technical work mostly followed the Terms of Reference (TOR) issued by the EC as a result from the “VVER-440/213 Bubble Condenser Qualification Feasibility Study”/TOR96/.

EREC work’s primary aim was to study the thermal-hydraulic processes and fluid-structure interactions of the components of a bubbler condenser system containment under conditions typically expected during postulated design basis Loss of Coolant Accidents (LOCAs).

The work performed at VÚEZ served the experimental qualification of the bubbler condenser mechanical structures, specifically for the ***Dukovany*** and ***Bohunice*** structural configuration. The static structural tests were primarily aimed to address some essential shortcomings identified by analytical assessments performed on behalf of a preceding comprehensive IAEA activity /IAE95a,b,c/. These studies concluded that stresses as hitherto predicted by strength analyses for certain parts of the bubbler condenser structure would exceed admissible values at distinct points. Certain structures even may fail in case of a large break loss-of-coolant accident (DBA-type accident).

Some small-scale tests and supplementary analytical studies have been requested from SVUSS in Prague (Czech Republic) with support from the Nuclear Research Institute in Rez (Czech Republic) and the VEIKI Institute, Budapest (Hungary).

Possible non-uniformities of flow rates and flow properties over the bubbler condenser tower height (stratification in vertical direction) were also the main objectives of several supplementary tests proposed by the Support Group in 1994. The need for additional integral large-scale confirmatory tests (the main objectives of a complementary experimental programme earlier foreseen to be executed in Zugres, Ukraine), was not confirmed by the EC Feasibility Study. The EC Study concluded these tests to be of lower priority, which might be carried out in a future supplementary test programme if a need would become again obvious.

4. Short description of the BCEQ test facilities

4.1 The EREC test rig

The EREC Test Rig aim was to investigate the thermal-hydraulic and fluid-structure interaction of the bubbler condenser system under conditions typically expected for LOCAs. For this purpose the EREC test facility has been designed, built and operated. It consists of the following main systems and components:

- a simplified room system simulating the hermetic compartment system of a typical VVER 440/213 containment upstream of the bubbler condenser tower

- a bubbler condenser test section consisting of 2x9 original sized gap-cap units, corresponding side walls, bottom and ceiling parts with mechanical properties identical to the ***Paks*** Nuclear Power Plant and a corresponding air space above the bubbler condenser water volume of the trays

- an air trap connected to the aforementioned air volume by a check valve

- relief valve to the BC shaft and a spray system providing the simplified room system with spray water

- a blowdown system consisting of 5 interconnected pressure vessels, pipe systems and blowdown nozzles to provide the necessary mass- and energy reservoir to simulate the anticipated LOCA blowdown rates at three different locations inside the compartments

- the necessary auxiliary equipment including instrumentation and the data acquisition system.

Other items characterising the EREC test facility are

- dimensioning of the blowdown nozzle derived on the basis of the scale results of ATHLET calculations for the anticipated failure conditions of the reference NPP

- preservation of the mechanical properties of the tray and the gap-cap systems, closely linked to the existing configuration of the ***Paks*** Nuclear Power Plant as one of the beneficiaries of the PHARE/TACIS project

- preservation of scale characteristic main volumes and/or flow areas of the prototype plant with limited modelling of the corridors between the steam generator boxes and the BC shaft

- scaling factor 1/100 for the design of the test rig volumes and the necessary mass-and energy reservoirs to simulate the variety of LOCA conditions

Supplementary scaling studies have been planned to support the correct interpretation of experimental results addressing in particular the transient mixing of the released steam with the air initially present in the hermetic compartment system and inside the corridor connecting to the tray system.

Existing differences between the structural design of the bubbler condenser trays of the ***Paks*** plants and those of the Czech and Slovak plants (***Dukovany***, ***Bohunice*** and ***Mochovce***) as well as of the ***Rovno*** and the ***Kola*** plants should be assessed by the contractors to warrant the general applicability of the expected test results.

A detailed description of the test rig has been provided in /BC-D-ER-SI-0002/.

The contracted preliminary test matrix consisted of 19 experiments, addressing global effects, vent clearing loads, effects during pool swell and condensation and loads during the reflux phase. The test matrix has been modified several times during the course of the BCEQ project. In an intermediate planning stage, it was already reduced to five LBLOCA tests (DBA-tests), two main steam line break tests (MSLB-tests) and at least one small break LOCA test /BC-D-ER-SI-0015/.

4.2 The VÚEZ test facility

The main objectives of the VÚEZ Test facility were to investigate the structural properties of the typical bubbler condenser steel structure under a sequence of quasi-static loading conditions up to 30 kPa typically expected for the most challenging conditions of a double-ended failure of a main recirculation line of a VVER-440-type PWR. Two experimental models were employed. The Bubbler Condenser Test Prototype (BCTP) served to verify the tray pressure-retaining boundary (front and side wall, ceiling and bottom) against the maximum expected differential pressure of 30 kPa. The Separate Model Test Prototype (SMTP) was focusing on the structural integrity of the gap-cap walls under non-steady loading conditions up to the anticipated maximum differential pressure of 30 kPa.

The VÚEZ facility consisted of the following main parts

- a 2x9 gap-cap system of original dimensions, fractional replica of the side and front walls, bottom and ceiling parts with boundary conditions, mechanical properties and strength characteristics identical to the NPP configurations
- a full size man hole of the ***Bohunice*** NPP
- a pressurisation system suitable to allow a stepwise pressurisation of the test rig up to the envisaged level of 30 kPa
- a pressure resistant containment housing the aforementioned test facility
- a so-called Separate Model Test Prototype (SMTP) designed and built to model 3 different types of gap-cap units with original dimensions and to allow their testing under quasi-static pressurisation conditions
- the necessary auxiliary equipment including instrumentation and the data acquisition system.

Analytical scaling studies should verify that the adopted mechanical boundary conditions of the selected test section do not influence the structural behaviour during the test to allow conclusions on the behaviour of the full-scale prototype plants. Further extensive analytical studies should accompany the test programme using non-linear elastic and/or plastic modelling capacities.

A detailed description of the test facility has been provided in /BC-D-VU-EA-0006/.

4.3 The SVUSS test facility

The aim of the SVUSS test facility was to provide small scale testing to support the selection and design of special instrumentation to be used in the EREC tests and to perform additional small-scale tests to answer possible questions in connection with the interpretation of EREC test results.

The facility is nearly identical to the previously existing test rig at ***Bechovice***, which had to be modified to serve the aforementioned purposes.

A detailed description of the test rig has been provided in /BC-D-SV-EF-0009/.

5. The BCEQ working method

According to the terms of reference (TOR) the contracted work addressed the following general items and goals:

- building or modification of existing test facilities
- construction of test prototypes
- execution of the qualification tests
- performance of pre-test and post-test analyses with appropriate computer codes
- generation of information adequate for an assessment by the Safety Authorities of the Beneficiaries of test methodologies, test programmes and representativeness of the results obtained.

The BCEQ Project was split into four main tasks:

Task 1: Management of the entire project (Leader: Siemens)

Task 2: Execution of the thermal-hydraulic and fluid-structure interaction tests at the EREC facility including the necessary analytical studies to specify the test rig design and to support the interpretation of the obtained experimental results (Leader: Siemens).

Task 3: Execution of the static structural test programme at the VÚEZ facility including the necessary analytical work to support the interpretation of the obtained experimental results (Leader: Empresarios Agrupados).

Task 4: Perform analyses of tests executed in task 2 and perform several small scale tests at the SVUSS test rig to support the development of specific instrumentation or monitoring systems needed for task 2 (Leader: Electricité de France).

A “Technical Advisory Committee” (TAC) has been established within the frame of the BCEQ Project. The aim of the TAC was

- to evaluate and discuss the progress made by the project
- to check that the results expected from the project will be accepted and validated remaining in compliance with the objectives of the project
- provide technical recommendations to the project co-ordinator
- finally, to recommend further tests to be performed on the same facilities, if necessary.

As foreseen in the Terms of Reference (TOR) three representatives of the OECD Support Group were associated to the TAC.

In parallel a “Users Team”(UT) was formed. It held its meetings in conjunction with the TAC meetings.

The BCEQ Project was started formally on 1 January 1995. However, due to the long tendering process and contract negotiations, actual work on the project began only in October 1997. At the end of the remaining work period of 27 months the Project had to be terminated on December 31,1999.

During the course of the project four TAC meetings were organised by the Project management to keep the TAC members informed about the progress of work. Meetings were held as follows:

1. meeting May 12-13, 1998 in Brussels
2. meeting November 17-18,1998 in Brussels
3. meeting September 28-30, 1999 in Elektrogorsk
4. meeting December 13-15, 1999 in Brussels (Final Meeting).

6. Achievements

The main results of the BCEQ Project have been summarised by the Consortium in the Final Project Report /BC-D-SI-EC-0535/. Additionally, a number of reports (so-called Deliverables) have been attached to the Final Project Report, which contain the detailed information on the performed works and on findings of the analytical and experimental studies.

Within the frame of the present "Situation Report" a detailed assessment of all the obtained experimental and analytical results and findings is not possible and was not envisaged. Due to the complexity of the problem, and in recognition of the considerable number of design and working reports, this will be the task for a follow-up TSO Project which should receive the necessary financial and manpower resources.

Here, we will focus on a couple of items, which became evident during the course of the Project, in particular on occasion of the informative TAC meetings. Four items have been selected which are considered important, having in mind the overall goals specified in the Terms of Reference (TOR) for the BCEQ /TOR96/.

Specific goals of the BCEQ Project were

- nuclear power plants of the Beneficiaries
- representativeness of the results for all bubbler condenser "operating conditions" (LOCA conditions)
- adequacy and representativeness of the results for concerned national Safety Authorities
- general suitability of experimental results for code validation and assessment

6.1 The Results of the EREC investigations (Task 2)

Construction of the EREC test facility started in May 1998 and was completed in June 1999. Because of unfavourable weather conditions and delays in release of EC funds, the completion of the test facility and the official facility acceptance meeting were delayed by 6-7 months as compared to the original working schedule. Under such circumstances it was not possible to execute all experiments as originally contracted, nor the reduced test matrix as modified during the course of the Project. Finally, only 3 typical large break LOCA tests could be performed within the remaining time frame of the Project. (For formal reasons the entire BCEQ contract had to be definitively terminated on December 31st 1999). The results of the experiments and the results of the pre- and post-test analyses performed by EREC in conjunction with the experiments have been reported in /BC-D-SI-EC-0028/.

The main experimental and analytical results of the EREC test campaign have been discussed within the frame of the 4th TAC meeting and on occasion of the OECD Support Group Meeting held in Berlin on 4-5 April 2000.

The 3rd TAC meeting was told that there would be no possibility to extend the duration of the Project, nor would it be possible to perform at least all tests envisaged in the frame of the interim test matrix. The remaining time before termination of the Project had to be used for post-test analyses and documentation of the work.

Three blowdown experiments were performed, which can be characterised as large-break LOCA tests. These tests differ from each other in terms of the location of the discharge nozzle (close or far from the corridor connecting to the BC simulator) and in the selected blowdown nozzle diameter.

At the final TAC meeting the Consortium concluded that the three EREC tests "conservatively reproduce the maximum thermal-hydraulic loads calculated" for the BCS configuration of the ***Paks*** Nuclear Power plant. An extended discussion focusing on this conclusion brought up a variety of counter-arguments:

- scaling of the "double ended-guillotine" failure test in EREC not necessarily reproducing anticipated bubbler condenser operating conditions (dimensioning the blowdown nozzle)

- reliability and relevance of measured energy discharge rates during the EREC experiments are questionable

- interpretation and relevance of the observed, but unexpected non-uniformities of flow rates in the corridor to the BC simulator and of the water temperatures on the BC trays for the prototype NPPs

- conservatism involved in the test conditions and design of the EREC test facility remains to be proven

<u>Concerning item 1:</u>

This question is closely connected to items 2 and 4. Observed maximum thermal-hydraulic loads on the containment structures are very closely determined by the applied energy discharge rates during the early part of a blowdown process. A 70 mm discharge nozzle was installed for test No. 5. The measured mass flow data are reliable only for a short time window between 0.4 sec (end of the acceleration phase) and 6-10 sec (beginning of two-phase flow conditions). Hence, the assessment of which test may have resulted in a "conservative" simulation of a double ended LOCA break for the bubbler condenser is difficult to prove and may only be possible on the basis of detailed analyses of the blowdown conditions and of the mass flow rates through the connecting corridor prevailing during the experiment.

<u>Concerning item 2:</u>

The mass flow monitoring sensors were located far upstream from the discharge nozzles and have not been complemented by a reliable density measurement device. Hence, the flow acceleration after opening the rupture disc cannot be measured, the early transient discharge rates into the containment remain unknown until quasi-steady flow conditions have been reached in the blowdown line. After onset of transient two-phase flow conditions the measurement of temperature and differential pressure is not sufficient to determine the energy flow passing through the pipe system. The missing density measurement in the blow-down line poses a decisive shortcoming in the interpretation and application of the EREC test results. This may even impede the future utilisation of the generated thermal-hydraulic containment data for containment code validation purposes.

In lieu of reliably measured blowdown conditions the Consortium proposed to provide the results of ATHLET calculations for EREC tests as relevant boundary conditions for the comparison of containment post-test calculation results with measured containment data. Moreover, ATHLET calculations should also support the interpretation of containment data for the application to the prototype NPPs. This proposal did not find unanimous agreement from all TAC members.

Concerning item 3:

The most interesting goal of the BCEQ Project was the investigation of the phenomena dominating the behaviour of the gap-cap system arrangement installed on the water tray. Non-uniformities of the flow conditions upstream of the tray, namely in the corridor connecting the simplified compartment model with the BC tray were observed. Flow conditions upstream of the bubbler condenser tray are important transient inlet conditions needed to correlate the observations on the tray.

Hitherto, all analytical simulation models were anticipating homogeneous flow conditions within upstream nodes and flow junctions. It is the observation of considerable non-uniformities of flow conditions in the corridor, which was not covered by the concept of modelling the bubbler condenser system. Moreover, non-uniformities have also been observed in the water temperatures on the trays. Also for this component modelling was based on the assumption of uniform temperatures on a particular tray.

Several questions concern the extrapolation of the EREC observations for the expected behaviour of a full size plant, which presently cannot be reliably answered without more or less speculating.

- Are the inhomogeneities of flow conditions in the corridor and further on of the water temperatures on the tray the result of the design and/or the mode of operation of the test rig?
- Would such non-uniformities become larger if similar tests would have been performed in (up to a factor 100!) larger test facilities or will they disappear?
- Will such non-uniformities become even more important if long-lasting and less turbulent small break LOCA tests would have been performed?
- Could the non-uniformity of water temperatures on the trays in combination with the non-uniformities of flow conditions in the corridor upstream of the tray promote the onset of local or global chugging processes?

Based on the overall conclusions and recommendations of the preceding TAC meeting held in Brussels an in-depth discussion of these items took place also on occasion of the 11th meeting of the OECD Support Group in Berlin in April 2000. Again, this discussion confirmed contradictory points of view among the experts, without leaving a feeling for eventual convergence of opinions at this point in time.

6.2 The results of the VÚEZ investigations (Task 3)

The VÚEZ contribution to the BCEQ Project started mid-November 1997 and was executed very closely to the original working schedule. The SMTP experiments were performed in full compliance with the test specification monitoring the applied transient pressurisation, resulting deflections and material strains at the predetermined locations of the experimental device.

The BCTP experiments were as well performed in full compliance with the specified procedures. Main parameters measured were the overpressure in the test arrangement, the resulting deflections and strains at pre-selected locations of the BCTP under stepwise pressure increase. Before reaching the requested maximum overpressure of 30 kPa the test had to be interrupted because of the formation of a leak between the manhole frame and the manhole door. After depressurisation the defect was repaired and the test was repeated up to the envisaged value of 30 kPa overpressure. The static structural test campaign has been described in detail in /BC-D-EA-EC-0015/.

The Consortium had drawn the following general conclusions concerning the experimental work and the associated pre- and post-test analyses performed at VÚEZ:

- The SMTP experiments and the associated analyses had demonstrated the integrity of the installed three different types of gap-cap systems and their capacities to withstand the requested differential pressure up to 30 kPa without loss of integrity.

- Non-destructive examinations of the welds performed after the test did not indicate the existence of cracks.

- Pre-test structure-dynamic calculation results were in good agreement to the measured values, which, however, had a tendency to be higher than the calculated values. Hence, the methods applied for pre-test calculations might not be considered “conservative”.

The BCTP experiments have demonstrated the preservation of the integrity of the pressure retaining boundaries (side and front walls, ceiling, bottom) of the tray levels 2 to 11 up to a differential pressure of 30 kPa. Side wall deformations are increasing with increasing pressure levels (buckling, larger non-elastic deformations above 24 kPa), but the welds remain integer. Under the conditions of the performed experiments no leaks occurred.

For the tray level 1 additional reinforcements have been recommended. For level 12 measures to reduce the differential pressures and/or additional reinforcements are under discussion.

Results of pre- and post-test analyses supporting the BCTP and SMTP experiments have been in good agreement with the measured strains and deflections. An updated material property curve had no substantial impact on the final stress and strain results. However, global deformations on the walls were predicted closer to the measurements as compared to a previously used material curve. The influence that the manufacturing and construction allowances had on the loss of wall stability makes it difficult to exactly predict the pressure level at which buckling will occur.

Due to the self-consistent concept of scaling and designing both test rigs (BCTP and SMTP) the relevance and applicability of the experimental observations to the conditions of real nuclear power plants appears to be less problematic as compared to the complex thermal-hydraulic experiments requested and performed within the EREC activity (task 2). The discussion of the well-structured and clear presentations on occasion of the TAC meetings did not disclose difficulties in understanding and interpreting the structural tests. In general they demonstrated agreement with the presented Consortium conclusions.

Earlier, similar pressurisation experiments have been carried out by VÚEZ within the frame of commissioning and licensing of the ***Mochovce*** nuclear power plant. The tests have been performed with the same pressurisation rates up to 150 kPa/s and up to a differential pressure of 30 kPa in an experimental set-up involving eight original gap-cap systems in a one-level arrangement with structures typical for the ***Mochovce*** plant. Some results of this activity have been communicated on occasion of a public Nuclear Society Information Meeting held in Levice (Slovak Republic) in November 1997 (NUSIM 97). These tests have also shown non-reversible plastic deformations of the cap sheet and the tray stiffeners. Static testing under gradually increasing overpressure resulted in plastic deformation of walls and some elastic deformations of bottom and ceiling sheets /FRE97/.

A full assessment of the results of the structural experiments performed by VÚEZ is expected to take place within the frame of a TSO activity and/or in the frame of national safety and licensing activities of the beneficiaries of the BCEQ.

6.3 The results of the SVUSS investigations (Task 4)

The primary objective of the contributions of SVUSS to the BCEQ was to support the main experimental programmes of the BCEQ carried out within the task 2 by performing thermal-hydraulic studies with appropriate computer codes. Secondly, some small-scale tests were carried out to support the design of specific instrumentation, e.g. visual monitoring systems /BC-D-SV-EF 0014/. Moreover, the requested calculations were performed to also support the arguments for the representativeness of the EREC experiments with respect to ***Paks*** and in particular their relevance for other NPPs with a bubbler condenser containment.

Unfortunately, collaboration between tasks 2 and 4 was hampered by the fact that task 2 work for various reasons was considerably behind schedule leaving little time for the exchange of information on design features and of the results of calculations between the partners EREC and SVUSS. E.g. in-depth investigations into separate effects emerging from integral experimental results of EREC tests were impossible. Optimum conditions for efficient collaboration were unfortunately not available.

Nevertheless, considerable analytical efforts have taken place at SVUSS to analyse various aspects of the anticipated LOCA behaviour of the ***Paks*** prototype plant. Calculation results served as basis for recommendations on the mode of operation of the EREC test facility, in particular for the energy supply system to predict the “relevant” blowdown flow rates scaled down to the dimensions of the EREC bubbler condenser test facility and to specify the maximum pressurisation rates which the bubbler condenser part of the containment should withstand during the envisaged tests.

Several calculation reports have been issued as deliverables documenting the selected analytical simulation concepts including the applied code versions, comparisons to NPPs, nodalisation schemes, and boundary conditions for the thermal-hydraulic simulation of the ***Paks*** prototype plant as well as of the EREC test facility, e.g. /BC-D-SV-EF-0011/.

The conclusions derived by the Consortium from these studies were subject to controversial discussions during TAC meetings as well as on occasion of the Support Group Meeting in Berlin, especially the direct applicability of thermal-hydraulic experimental results to full-size NPP conditions.

In this context it was considered important to firstly assess in-depth the decisive scaling factors which apart from the applied concept of “volume / energy” scaling determine various other transient two-phase flow phenomena involved in the bubbler condenser system functions, e.g. the observed formation of non-uniformities of flow properties at the inlet to the tray and within the extremely short corridor between the two compartments and the tray. Unfortunately, the interpretation of the experimental results has become even more complicated through the coupling of the simulation of the cooling system of the NPP to the simulation of the bubbler condenser containment system by the unreliably monitored two-phase blowdown process.

7. Associated TSO activities

The Technical Safety Organisations (TSO) Group is assisting the European Commission (EC) in matters of reactor safety. In December 1997 a specific TSO Project SK/HU/CZ/TS/08 has been started to accompany the industrial PHARE/TACIS Project PH 2.13/95. The main objective of this project was to provide support to the national Regulatory Authorities and their safety organisations (responsible for the operation of VVER power plants) in terms of the evaluation, implementation and assessment of the experimental and analytical results of the BCEQ.

The contractor of the TSO Project SK/HU/CZ/TS/08 was RISKAUDIT, Paris; the Western subcontractors were GRS (Germany) and AEA Technology (Great Britain). The local Eastern subcontractors were NRI, Rez (Czech Republic), SEC NRS Moscow (Russia), VEIKI Budapest (Hungary) and VÚJE Trnava (Slovak Republic). The project was limited to 12 months duration.

The design concepts of the three test facilities (EREC, VÚEZ and SVUSS) participating in the Project, the proposed experiments and the associated pre-test calculations have been reviewed by the TSO project. The basis for this review has been the status of the BCEQ Project as presented at the second BCEQ-TAC meeting in November 1998. Unfortunately, outside TAC meetings the flow of information from the BCEQ Project to the TSO Project has been poor. The resulting lack of data has complicated the requested assessment by the TSO staff of the design of the test rigs, of the proposed experiments and in specific of the pre-test calculations.

Nevertheless, the review has been successfully completed, based largely on the results of independent calculations performed in the frame of the TSO Project. The scope of these calculations has been comprehensive. The response of the involved test facilities to envisaged typical experimental conditions has been studied. In addition, large break loss of coolant (LBLOCA) and main steam line break (MSLB) accident scenarios have been analysed for the NPPs in order to address issues of scaling and to attempt to check whether the foreseen experiments will cover an appropriate range of conditions.

The main reason for the poor communication between the BCEQ and the TSO Projects was the lack of any formal link between both Projects foreseen in the Terms of Reference of the BCEQ Project. As a consequence, no response from the BCEQ Consortium to information provided by the TSO Project has taken place. Moreover, the TSO staff did not receive any direct feedback from the BCEQ Consortium concerning the recommendations given by the TSO Project in both the Interim and the Final Reports /WOL98/.

Summarising the results of the TSO Project the following information has been provided during the OECD Support Group meeting in Berlin in April 2000:

<u>Review of the BCEQ Work Plan and the Quality Assurance Programme</u>

- The work plan was found to be in accordance with the TOR of the BCEQ Project and the results of the Feasibility Study addressing the most important phenomena identified by the OECD Support Group. Other open safety issues raised by relevant IAEA studies related to VVER-440/213 plants were addressed as well. The work plan was found to be extremely tight, not allowing any delays for whatever reason.

- The Quality Assurance Programme was found to comply with relevant international standards.

Analytical Support and the Small Scale SVUSS Test Facility

- An assessment of the documents made available to the TSO Project revealed the instrumentation and the data acquisition system (DAS) to be inadequate, needing improvement. The test matrix was found to be incomplete leaving the entire small-scale test programme - as described by the TOR of the BCEQ Project - questionable with respect to the relevance to Nuclear Power Plants. Appropriate TSO recommendations had been formulated and forwarded to the BCEQ Project.

- Results of the BCEQ pre-test analyses were not made available. Hence, independent TSO calculations were performed indicating a strong need for an exact measurement of the as run mass- and energy release rates.

EREC Large Scale Test Facility

- The global scaling of the design concept was found to be properly treated, but possible differences of the structural behaviour were identified. Based on poor descriptions of the envisaged EREC instrumentation, e.g. for the gas shaft and the blowdown line, recommendations for an improvement of the instrumentation and the data acquisition system have been provided. The test matrix was found to be incomplete, resulting in further recommendations to the BCEQ Project.

- No information was given at that time concerning the test procedures, only little information on performed pre-test calculations. Independent preliminary ATHLET/RALOC calculations to compare the thermal-hydraulics of the EREC test facility with the NPP were performed for the MSLB case, and for the LBLOCA situation of the NPP only. Regarding the importance of the mass- and energy discharge rates for the interpretation of the foreseen experiments it has been proposed to perform a series of pre-operational tests in combination with iterative analyses of the behaviour of the pressure vessel system during blowdown serving as the experimental energy source.

VÚEZ Static Structural Test Facility

- The facility was considered to be accurately scaled, however locations and pressure levels resulting in possible structural failures in the NPP were expected to be different. The instrumentation and the Data Acquisition System were assessed as reasonable and suitable. A comparison of pre-test calculations performed by the BCEQ and TSO Projects showed small differences, except for predicted stresses in large side walls which were three times higher in the TSO analyses.

As the first out of three phases agreed upon with the European Commission, the TSO Project SK/HU/CZ/TS/08 was terminated in December 1998. So far, no further TSO activities have been contracted with the EC, however.

As a consequence, no final assessment of the analytical and experimental investigations performed within the frame of the BCEQ Project has yet been achievable, although the acceptance of the generated BCEQ results by the concerned national Regulatory Authorities would require such an in-depth assessment. In view of the importance of the bubbler condenser containment system for the safety of a Nuclear Power Plant of the VVER440/213 type a continuation of the TSO activities is deemed indispensable.

8. 0verall conclusions related to the understanding of the containment with Bubbler Condenser System

Summarising the above discussions and observations the following conclusions and recommendations may be drawn with respect to the usefulness of the BCEQ Project and the complementary TSO activity:

- It must be noted that only a small fraction of the contracted EREC test matrix had been executed before termination of the BCEQ Project.

- The discussions of the main findings of tasks 2 and 4 of the BCEQ Project during the TAC meetings and the Support Group meeting in Berlin in April 2000 have evidenced contradictory points of view amongst the experts.

The main points of divergent opinions are related to the following items:

1. The primary purpose of thermal-hydraulic experiments in the area of nuclear safety was always to serve validation and verification of codes and/or code application concepts (the Analytical Simulation Models) which finally may be applied to predict thermal-hydraulic phenomena in full-size Nuclear Power Plants important for their reactor safety functions.

2. Pending detailed analyses of the blowdown discharge rates obtained during the LBLOCA tests at EREC, these tests may indicate that the maximum differential pressure of 30 kPa indeed covers the ultimate pressure loading cases.

3. Additional work is still necessary to reach a comprehensive understanding of the containment with bubbler condenser structures. In particular, the phenomena dominating small and intermediate break size LOCA situations remain to be addressed in additional testing. The probability of such scenarios will be larger than that of a large break LOCA. During a Small Break LOCA the occurrence of flow conditions promoting the onset of oscillatory condensation and even chugging will be more likely and the duration of such situations under SBLOCA conditions will be much longer.

4. Substantial work would be needed to understand the reasons for the observed non-uniformities in a test rig which is much smaller compared to the containment system with bubbler condenser of a full-size NPP in order to assess their importance for containment safety. The applied concept of volume scaling certainly will not address the formation of non-uniformities of two-phase flow conditions and of the condensation phenomena on the trays. Additional similarity considerations are needed to address mixing and transport phenomena obviously influencing the transport of steam/air mixtures into the tray.

5. The results of the quasi-static tests performed at VÚEZ in context with task 3 obviously are less difficult to interpret and extrapolate to a prototype NPP due to the chosen test rig concept and the applied testing procedures. The quasi-static nature of the structural tests performed in the frame of the VÚEZ activities in combination with the installation of original structures of the gap-cap systems and of the confining walls with original material properties allows to conclude on similar stress/strain mechanics behaviour of the NPP bubbler condenser structures under equivalent loading conditions. However, the representativeness of the 30 kPa value for the maximum differential pressure and of the failure location to which the VÚEZ test rig has been subject remains to be definitively proven.

6. In this context, the TSO providing technical support to the regulatory authorities of the Beneficiaries may play an important role to resolve the aforementioned divergent points of view.

9. Recommendations

The OECD Support Group recommends undertaking the following work:

- Further post-test analyses of the results obtained so far should be performed, to decide about future DBA (Design Basis Accident) or BDBA (Beyond Design Basis Accident) experimental/analytical activity and with a view to understanding of non-uniformities in temperature and flow distributions observed in the experiments.

- Post-test calculation results should be used for the bubbler condenser design qualification and for code validation and improvements, in order to model the phenomena occurring in the bubbler condenser.

- Further testing should be performed for the main steam line break (MSLB), for medium and small break LOCA accidents in order to better understand non-uniformities.

- In parallel with these efforts the Support Group recommends further bubbler condenser investigations to be performed for the ***Kola*** nuclear power plant.

The OECD Support Group also recommended assigning priorities to the proposed work:

- After reassessment, considering both the analytical and experimental results of the BCEQ tests, a first step should be to perform as soon as possible post-test analyses of available results. In addition to providing better understanding of the phenomena, which had occurred during the tests, such work would also help identify necessary improvements in instrumentation. (It was not excluded that post-test analyses would demonstrate the need for additional tests).

- A second high priority should be assigned to the investigations of non-uniformities in temperature and flow velocity distributions.

- Regarding further testing, the nineteen-test matrix developed previously was still valid, as shown by the Support Group discussions. A first step would be to perform pre-test calculations for the remaining tests. It was hoped that some of these tests could be carried out in a not too distant future.

- In parallel to these efforts a high-priority TSO project should primarily assess the aforementioned items of interpretation and extrapolation of the BCEQ Project results before a definitive safety assessment of the containment with bubbler condenser, also regarding related safety improvement actions, should be released.

Moreover, the OECD Support Group recommended official transmittal of the minutes of its Berlin Meeting to the European Commission.

10. Closing remarks

The OECD Support Group on “VVER-440/213 Bubbler Condenser Containment Research Work” will continue to be ready to monitor the progress of further bubbler containment research and assessment work, and promote both analytic and experimental efforts, needed to close the issue. In doing so, the OECD Support Group will endeavour to use the available resources effectively and to avoid duplication of efforts.

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