EUROPEAN COMMISSION
DIRECTORATE-GENERAL JRC
JOINT RESEARCH CENTRE
Institute for Energy
Technical and Scientific Support to TACIS and PHARE

TACIS NUCLEAR SAFETY

TACIS PROJECT R8.01/97

TRANSLATION, EDITING AND DIFFUSION OF DOCUMENTS

(Results Dissemination)

TACIS R2.31/94 Project

LEAK BEFORE BREAK CONCEPT APPLICABILITY EVALUATION (RBMK REACTORS)

EXECUTIVE SUMMARY

TSSTP/DISS97/02 02 012	Petten, 2002/02/19

Author(s):	**R. AHLSTRAND**	**(EC/JRC-IE)**
	V. KISELYOV	**RDIPE**
Reviewed by:	C. RIEG	**(EC/JRC-IE)**
Approved by:	M. BIETH	**(EC/JRC-IE)**

ABSTRACT

This dissemination report summarises the Tacis NUCRUS 94231 project entitled: Leak Before Break Concept Applicability Evaluation (RBMK Reactors), which has been completed as specified in the Technical Terms of Reference of the project. The report was compiled on the basis of Final Report prepared by Jussi Solin and Heikki Keinänen (VTT Manufacturing Technology), Espoo, Finland, June 1998. The report summarises the main objectives and key results of the project.

A complete deterministic evaluation of the leak before break safety concept was performed for the large diameter (ϕ800 mm) main coolant circuit (MCC) piping of the selected Reference Unit, Smolensk-3. The LBB concept is considered applicable for this studied case. All the structural materials used for the fabrication of large diameter MCC piping are ductile at operational temperature ranges. The structural validation test performed was successful in demonstrating LBB conditions and the full-scale component behaved in a ductile manner at room temperature. Sufficient safety margins in relation to fatigue crack growth, crack initiation and catastrophic failure were indicated.

An overview of the project with the conclusions and recommendations is given in this report.

PREFACE

The report has been prepared to demonstrate the results of the Tacis NUCRUS 94231 project entitled: Leak Before Break Concept Applicability Evaluation (RBMK Reactors). The project has been completed as specified in the Technical Terms of Reference (TOR). All the deliverables specified in the TOR were prepared and the objectives of the project were successfully accomplished.

The Contractor of the project was VTT Manufacturing Technology. The Beneficiary, or Local Operator, was Rosenergoatom and the Research and Development Institute of Power Engineering (RDIPE) was the Local Subcontractor. AEA Technology plc and Siemens KWU joined the project team as Subcontractors.

The Russian research organisations participating in the project under the leadership of RDIPE were CNIIKM “Prometey Institute”, MoAEP, NPO CKTI “Polzunov Institute”, NPO SNIITMASH, RSC “Kurchatov Institute”, VNIIAES and VNIPIET. The Western participants were VTT Manufacturing Technology, AEA Technology plc and Siemens KWU.

The project was divided into eight Tasks. The Task Leaders were Jussi Solin / VTT Manufacturing Technology (1,8), Timo Saario / VTT Manufacturing Technology (2), Peter Hurst / AEA Technology plc (3), Heikki Keinänen / VTT Manufacturing Technology (4), Laurence Gardner / AEA Technology plc (5), Peter Conroy / AEA Technology plc (6) and Ulrich Kunze / Siemens KWU (7).

The joint kick-off meeting of the project took place at VTT Manufacturing Technology in Espoo, Finland on 18 June 1996, and the final Steering Committee meeting at RDIPE in Moscow, on 4 June 1998.

This report has been compiled on the basis of the final report prepared by Jussi Solin and Heikki Keinänen / VTT Manufacturing Technology. The Task Leaders and experts, particularly, John Sharples / AEA Technology plc, Vitaly Kiselyov and Sergey Evropin / RDIPE participated in the editing of the final report.

The Steering Committee and all the Project Partners - AEA Technology plc, RDIPE, Siemens KWU and VTT - have accepted the final report. The efforts of each organisation and expert were greatly acknowledged and the kind co-operation of Rosenergoatom and Smolensk NPP was gratefully appreciated.

The local team (RDIPE) has strong experience in all aspects of structural integrity and LBB assessment of the RBMK types of reactor.

CONTENTS

1 INTRODUCTION

1.1 General Background

The concept of leak before break (LBB) has gained considerable worldwide momentum in recent years in establishing safety cases for pressurised components particularly in the nuclear industry for piping in all types of reactors. Such a concept is aimed at demonstrating that leakage of an appropriate gas or fluid through a crack in the wall of the component can be detected prior to the crack attaining conditions of instability at which rapid crack extension occurs. LBB arguments may be used as a part of the case for the elimination of pipe-whip restraints, be applied in regions which are difficult to inspect, due to inaccessible or hazardous conditions and/or be applied as defence-in-depth considerations.

The LBB concept is very important for the NPP safety considerations. For high energy piping systems in particular, it is of great value to assure that LBB conditions prevail and thus catastrophic failure can be avoided. For this purpose various methods for LBB have been developed in many countries operating NPPs. The LBB concept is applied e.g. in Bulgarian, Czech, Slovak and some Russian VVER reactors.

The first priority of this project was to examine the large diameter (ϕ800 mm) RBMK main coolant piping. The situation of the other important components such as the steam separators and smaller diameter piping with respect to LBB will be examined in succeeding projects.

1.2 RBMK Reactor Unit

The RBMK primary circuit is a rather complex structure with respect to both layout and materials used. The main coolant circulation circuit (MCC) is comprised of two symmetrically arranged separate loops. The partial conversion to steam occurs in more than 1600 fuel channels that are fed from the pressure headers. The dry steam is separated from and the turbine condenses are pumped back into the steam separators. From the steam separators the coolant flows through multiple downcomers to the suction header. The main circulation pumps (MCP) and the ϕ800 mm bore piping feed the coolant between the ϕ900 mm suction and pressure headers.

Some primary components and piping are situated outside the confinement. The design basis of the first generation plants does not include breaks of ϕ800 mm piping and the safety systems are not designed to cope with such failures. Breaks in the 800 mm diameter piping could lead to a failure of civil structures in the first generation plants. The design of later RBMK plants concedes that the 800 mm diameter piping breaks with respect to the capabilities of the ECCS and ALS systems. Moreover, there are no pipe whip restraints; jet shields and the components are separated to a limited extent only. The limited space between the piping gives some cause for concern. Successful application of the LBB concept is therefore considered of a high priority since it would ensure a low risk of breaks in the large diameter high energy piping, and provide the operator with an early warning before a major break could develop.

2 OBJECTIVE AND IMPLEMENTATION

The main objective of the project was to accomplish a complete deterministic evaluation of leak before break safety for the large (800 mm diameter) main coolant circuit piping of the selected Reference Unit, Smolensk-3.

The project was realised in eight Tasks, which are briefly described in this chapter. The main results within each Task are summarised in the subsequent chapters.

2.1 Task 1: Project Management and Definition

The main objective was to collect basic design data, a glossary of terms and to select a suitable Reference Unit and the structural features to be subjected to LBB evaluation. The Task included the following sub-tasks:

Task 1.1 *Production of a project work plan, time schedule and project related QA programme;*

Task 1.2 *Statement of methodology and conditions;*

Task 1.3 *Supply of basic design data;*

Task 1.4 *Selection of structural features;*

Task 1.5 *Glossary of terms;*

Task 1.6 *Project management, monitoring, reviews and reporting.*

2.2 Task 2: Material Properties Assessment

The principal objective of this Task was to provide additional description of materials used in the MCP piping of the reference unit Smolensk 3, the fabrication, welding methods and heat treatment in particular. The material and weldment properties required for the structural analyses were compiled. Materials testing was performed to determine crack growth resistance characteristics. The sub-tasks were as follows:

Task 2.1 Description of materials and fabrication;

Task 2.2 Compilation of materials properties database;

Task 2.3 Materials testing;

Task 2.4 Review of the results and report on Task 2.

2.3 Task 3: Evaluation of Operational Monitoring

The main objective of Task 3 was to review the previous operating history and water chemistry of the Reference Unit (Smolensk 3) to determine whether the conditions satisfy those necessary for leak before break behaviour. The following sub-tasks were included:

Task 3.1 Evaluation of Reference Unit operation history and environment;

Task 3.2 Identification of known leakage problems and defects;

Task 3.3 Review of the results and report on Task 3.

2.4 Task 4: Technical Analyses

After the LBB candidate piping was reviewed for degradation mechanisms and found to be acceptable in Task 3, it was subjected to a fracture mechanics evaluation in Task 4. The purpose of this evaluation was to show that there is flaw stability and that the resulting leakage will be detected in the event that a through-wall flaw would develop. The specific objectives of Task 4 were:

- to ascertain the information that already exists about structural analyses connected to RBMK LBB of the Smolensk NPP unit 3;
- to verify the validity of the structural analyses performed;
- to carry out further technical analyses for assessment of RBMK LBB safety of the Smolensk NPP unit 3.

Task 4 included the following sub-tasks:

Task 4.1 Review of existing analyses;

Task 4.2 Stress analysis;

Task 4.3 Fracture mechanics and crack opening area calculations;

Task 4.4 Leak rate calculations;

Task 4.5 Consideration of uncertainties and other factors;

Task 4.6 Review of the results and report on Task 4.

2.5 Task 5: Experimental Validation of LBB by Large-Scale Testing

The objective of Task 5 was to obtain experimental support for the LBB applicability evaluation. The first aim was to collect and review the existing information about the structural tests carried out in support of RBMK reactors in relation to its contribution to validating the LBB analyses of the Reference Unit. Further structural test with supporting analyses was to be carried out. The following sub-tasks were thus included:

Task 5.1 Review of Previous Large Scale Tests;

Task 5.2 Specification of Requirements for Additional Tests;

Task 5.3 Structural Testing;

Task 5.4 Review of the results and report on Task 5.

2.6 Task 6: In-service Inspection

The purpose of the in-service inspections is to demonstrate that defects do not exceed the critical flaw size between periodic inspections. In the context of LBB, it was necessary to demonstrate that no long cracks exist in the welds of the large bore MCC piping.

The first objective of Task 6 was to evaluate the regions of the MCC piping which are not inspected because of limited access and other limitations, and to identify the regions that are not inspected in an optimal way. Another objective was to evaluate the defect detection capability of the current in-service inspection and also to assess and demonstrate the sizing performance of selected advanced sizing systems. Finally, suitable recommendations regarding the implementation of upgraded inspection systems were targeted. The Task consisted of the following sub-tasks:

Task 6.1 Production of Inspection Maps;

Task 6.2 Demonstration of upgraded inspection procedures;

Task 6.3 Review of the results and report on Task 6 with recommendations for implementation of upgraded inspection systems.

2.7 Task 7: Leak Detection and Condition Monitoring Systems

The objective of Task 7 was to analyse the RBMK reactor with regard to leakage detection and load monitoring. This analysis would be compared with the present status of world wide existing leakage monitoring and condition monitoring systems to enable an assessment of the most appropriate systems to be used in support of the LBB concept. The Task included the following sub-tasks:

Task 7.1 Review of adequacy of existing systems for LBB safety concept applications

Task 7.2 Demonstration of upgraded leak detection systems

Task 7.3 Demonstration of upgraded condition monitoring systems

Task 7.4 Review of the results and report on Task with recommendations for implementation of upgraded leak detection and condition monitoring systems.

2.8 Task 8: Evaluation of Leak before Break Safety Case

The objective of this Task was to draw together and report the obtained results for delivering the conclusions, limitations and recommendations on the LBB safety case. The sub-tasks were:

Task 8.1 Preparation of final report;

Task 8.2 Statement of conclusions, limitations and recommendations;

Task 8.3 Glossary update.

2.9 Delivery of the Project

The project has been completed as specified in the Technical Terms of Reference (TOR) of the project. All of the 18 specified deliverables were prepared as indicated in Table 1. A total of 2240 pages in 62 reports have been prepared. Part of the reports are translated into Russian.

The objectives of the project were successfully accomplished. A complete deterministic evaluation of leak before break safety was performed for the large (800 mm diameter) main coolant circuit piping of the selected Reference Unit, Smolensk-3.

Table 1 List of Supplied Deliverables and References to the Reports List

Deliverable	Task	Description	References
1	1.1	Project plan, time schedule and QA programme	1,5,6
2	1.2	Statement of methodology and conditions for leak before break concept applicability evaluation	1,7,8
3	1.3-4	Report describing reference unit and selected features	2,9,10
4	1.5	Glossary of terms	3,12,13
5	2.1	Report describing materials and fabrication	11,14
6	2.2	Material properties database	15,17
7	3.3	Report on operating history, leakage problems and defects	21,22,23
8	4.1	Review of existing analyses with specifications for new analyses	24,27
9	4.6	Report on the technical analyses	25,28,29,30, 31,33,34,35
10	2.4	Report on materials testing	16,18,19,20
11	5.1	Review report on validation by structural testing	36,38
12	5.2	Specifications for structural testing	36,39,40,41
13	6.1	In-service inspection maps	43,45,46
14	6.3	Report on ISI systems and recommendations for upgraded ISI systems implementation	44,47,48,49, 50
15	7.4	Report on adequacy of leak detection and condition monitoring systems for LBB and recommendations for their improvement	51,52,53,54
16	5.4	Report on the structural testing	37,42
17	8	Final report on the LBB case with recommendations; Glossary update	56,57
18	1.6	Progress reports to CEC as required by GTOR	4

3 PROJECT DEFINITION (TASK 1)

Deliverables 1, 2, 3, 4, 18 [1,2,3,4] and a total of 21 reports originated from Task 1. The general conclusions concerning the work in Task 1 were as follows:

- A detailed work plan suitable for execution of the project was included in the inception report.
- Smolensk NPP Unit 3 was chosen as the reference RBMK 1000 unit. It is emphasised that the LBB analysis shall be unit specific and the results of this project shall not be directly generalised for application in other units.
- After careful consideration, a European LBB procedure based on the report Siemens KWU NT 13/96/E046 was chosen as the methodology to be applied for the evaluation of the applicability of LBB concept for the reference RBMK 1000 unit, Smolensk NPP Unit 3.
- For comparison, the US NUREG 1061 methodology was applied. In practice, the German methodology is more suitable for assessing multiple potentially critical sites in the RBMK MCP piping systems.
- The stress analyses and fracture mechanics analyses were recommended to concentrate both on the circumferential and axial bimetallic welds identified as potential critical sites for LBB.
- The preliminary analysis indicated four critical locations representing potential sites for analysis of LBB behaviour. They are welds joining pipes to the main circulation pumps (MCP), pipe to elbow, pipe to valve, and pipe to header.
- The on-site welded circumferential weld 21-5 in MCP 21 suction line is a potential site to have a minimum safety margin to LBB. However, final judgements could not be made before the material properties are collected in Task 2 and further analyses are performed in Task 4.
- The preliminary version (revision 2) of the compiled glossary was sufficient for the aims of the current project and an agreement on the meaning of the terms was reached between the parties. The Russian language counterparts of the terms are included in the glossary. The glossary should be maintained as the project progresses and the final updated version (revision 3 or more) should be published later in the project.

The Inception report with all its annexes [5,6] covers the results of Task 1.1. The report of RDIPE [7] referring to a report by Siemens [8] covers the results of Task 1.2.

Basic design data on the components of the large bore piping between the branches of the pressure/suction headers and the main coolant circulation pumps, and general information on the plant and its operation was provided in a report [9]. A review of the report was performed [10] and further information to select the most appropriate structural feature was obtained [11].

The relevant technical terminology on RBMK reactors and LBB methodology to be used in the current and forthcoming projects was specified [12,13].

4 MATERIAL PROPERTIES ASSESSMENT (TASK 2)

Deliverables 5, 6, 10 [14,15,16] and a total of 8 reports originated from Task 2. The general conclusions concerning the work in Task 2 were as follows:

- All the structural materials used for the fabrication of the large diameter MCP piping are ductile at operational temperature ranges.
- The manufacturing, fabrication and installation were carried out in accordance with relevant regulatory documents. After manufacturing, the base metal and weld materials were subject to destructive testing. After fabrication and installation total (100%) pre-service inspection and non-destructive examinations were performed.
- The database of the available material properties for the MCP large diameter piping of Smolensk 3 has been compiled [17]. Analysis of the data showed that the mechanical properties of the base and weld metals for the Smolensk 3 ϕ800 mm MCP piping were better than the guaranteed properties defined in the specifications.
- Almost no difference was found in the results for longitudinal and perpendicular direction of rolling, i.e. the material properties are quite isotropic.
- The results compiled indicated that Creuzelso 330E shows ductile behaviour throughout the operational temperature range, and that the mechanical properties meet the requirements defined by the specifications set in the relevant Russian regulations.
- Mechanical properties of archive material from Smolensk 3 MCP piping were determined. Based on Task 2.1 and Task 2.2, additional materials testing was needed mainly in determining fracture resistance J-R-curves at the temperature of 285^{o}C. Also the nil-ductility temperature (NDT-T) should be verified using the drop-weight testing method. [18]
- The test results from both RDIPE [19] and Siemens KWU [20] confirmed the preliminary conclusion from Task 2.1 and Task 2.2 that both the weld and base metal of the piping material are ductile at the operating temperature of 285^{o}C. Additionally, the nil-ductility

temperature (NDT-T) was as low as -50°C, indicating that the piping material behaves in a ductile manner at all temperatures from room temperature to the operating temperature.

- Comparison of RDIPE and Siemens results on fracture resistance J-R-curves showed that the results are consistent. Based on previous experience on J-R-curve determination, the results from both organisations are to be considered representative and to fall into a common scatter band with a normal scatter of about 5 to 20 % around the average value showing no systematic differences in results gained by the two organisations.

The report [11] describes the fabrication and welding procedures as well as heat treatments used to produce the piping from bimetallic sheet originating from Creuzo-Loire, France. The report also gives the chemical composition as well as the guaranteed values of the mechanical properties of base metal Creuzelso 330E and weld metals including ETNA-52HR, SF-2+SP601 and UONI 13/55. Additionally, the fatigue crack growth rate of Creuzelso 330E and ETNA-52HR are given for temperatures 20°C and 350°C, together with the fracture toughness values of the same materials for the brittle to ductile transition temperature range (-180°C to +20°C).

The report of RDIPE [17] provided a compilation of materials properties database associated with the Reference Unit. The scheme of Suction, Pressure and MCP by-pass welded joints for Smolensk 3 was given too. Basic dimensions of straight pipes and elbows, equipment and valve nozzles for shop and site joints in the ϕ800 mm pipelines are given together with the distribution of weld types in each loop of large diameter piping of Smolensk 3. The reference material properties database is given.

The report also gives the temperature dependencies of the mechanical properties (R_m, $R_{P0.2}$, Z and A) and the impact test results (KCV, percentage of ductile fracture).

5 EVALUATION OF OPERATIONAL MONITORING (TASK 3)

Deliverable 7 [21] and a total of 4 reports originated from Task 3. The general conclusions concerning the work in Task 3 were as follows:

- No significant degradation mechanism has been identified as having degraded the ϕ800 mm piping of the reference plant.

- Environmental cracking is considered to be very unlikely, which is confirmed by operational experience of the RBMK reactors. However, a review and/or experimental study would be of interest to confirm whether stress corrosion cracking or corrosion fatigue could be possible in unexpected adverse combinations of metallurgical structure of materials, water chemistry and loading conditions. With this recommendation, which would confirm that environmental cracking mechanisms could not operate, and a continued plant surveillance programme it is concluded that the ϕ800 mm piping circuit can be considered for the application of LBB analysis.

As agreed [22], RDIPE provided a report [11] on evaluation of the integrity and operation history of large diameter primary circuit piping associated with the Reference Unit. The AEA Technology report [23] summarises and reviews the information provided [11,17] and falls into two parts.

In the first part, information concerning plant materials, water chemistry specification and operational history is summarised. An evaluation of the susceptibility of the piping to degradation mechanism such as erosion, corrosion, water hammer, and stress corrosion is made.

In the second part of the report, the information is reviewed. Environmentally assisted cracking is identified as being the potential degradation mechanism of most concern. The susceptibility of the circuit materials are assessed and stress corrosion cracking is considered unlikely.

6 TECHNICAL ANALYSES (TASK 4)

Deliverables 8, 9 [24,25] and a total of 9 reports originated from Task 4. The general conclusions concerning the work in Task 4 were as follows:

- The adequacy of the incorporated current margin of 2 on through-wall detectable crack length (against failure) and the current (total) margin of 10 on leak rate and leak detection capability was evaluated from considering the uncertainties. A residual margin of 1.3 remains to account for additional uncertainties in estimates of maximum load-carrying capacity of the cracked pipes, and a reserve margin of 3.1 remains to account for additional factors and uncertainties affecting the leak rate.

- The ECCS water is injected through the distribution group headers and inlets to reactor channels. From channels the water flows to steam separators and the ECCS water reaches the ϕ800 piping in a later phase of cooling. Thus, the emergency cooling condition has not been analysed.

- The headers and the MCP cups are fixed in the centre cross sections to civil structures. The displacement boundary conditions for MCP piping should be rather well defined.

However, to define the real structural behaviour of piping, questions concerning the exact behaviour of piping spring supports and suspension remain.

- The weld with the smallest safety margin is not necessarily identical to the maximum loaded weld.

- A minimum safety factor value of 3.4 for circumferential cracks was obtained for the moderately loaded circumferential site weld No.24-5 in the MCP-24 suction line instead of the originally assumed weld No.21-5 in the MCP-21 suction line. The adequacy of the current safety margins was evaluated also by considering the uncertainties and other factors affecting the technical results.

- The intention was to assume conservative boundary conditions concerning applied resultant forces and moments in the analyses. A conclusive confirmation or need of experimental measurements is not considered here.

- On the basis of the assessment carried out by stress analysis, fracture mechanics, thermal hydraulics and leak rate calculations, the 800 mm diameter MCP piping meets all the LBB criteria.

The LBB approach was based on the methodology developed in Germany [7,8]. The US NUREG 1061 methodology [26] was applied for a comparison.

The results concerning the existing analyses have been presented in [27]. The stress analyses were performed by Russian codes and different calculation schemes depending on which part of the main circulation circuit (MCC) piping was considered.

A new stress calculation was performed to define inner loads and stresses in the Smolensk-3 MCC piping. Stress analysis was performed corresponding to normal operating conditions and safe shutdown earthquake loads [28]. For comparison, stress analysis was performed by several codes. As a result the values of inner forces and moments were presented for different loading situations. Strength assessment of MCC piping was also performed.

Reference elbows for detailed analysis were selected according to the results of general stress analysis [29]. Stress analysis was performed for the forces and pressure corresponding to normal operating conditions and the combination of normal operation conditions plus safe shutdown earthquake.

The critical crack length and leak area calculations were made both for maximum loaded and moderately loaded welds by using conservative engineering methods [30]. Fatigue crack growth analysis was performed for the highest loaded circumferential site weld 21-5.

Sub critical crack growth of an initial flaw due to normal operation conditions loading was calculated using the Swedish SACC code.

The longitudinal welds 289-290 of the elbow in the suction pipeline near MCP-21 were considered in the finite element analysis [31]. The measured unit specific archive material stress-strain and J-R curves were used in the analysis.

The leakage analyses were carried out using the SQUIRT code [32]. The crack dimensions (crack opening vs. length) were initially calculated for all relevant longitudinal cracks by using the computer code "FLEC".

For conservative safety margin estimations, the critical crack length calculations for normal operation conditions plus safe shutdown earthquake (SSE) were combined with lower-bound stress-strain curves of the relevant materials. Upper bound values were used for the leak rate calculations.

LBB analysis for site circumferential weld 21-5 in the MCP-21 suction line of Smolensk-3 was also performed according to NUREG-1061 (US NRC) procedure [33,34]. The fracture mechanics analyses were carried out on the basis of three dimensional elastic-plastic finite element analyses.

In all cases analysed the LBB conditions were fulfilled. The results of critical crack lengths and corresponding leakage sizes for cracks in the circumferential and longitudinal welds are summarised in [35].

The LBB argument is not and never will be absolute, because there always remain some uncertainties relating to it. Therefore, it was necessary to consider all these uncertainties and variations in the input parameters and to assess their influence on LBB behaviour [35]. A simplified approach for LBB safety margin evaluation was applied.

In general, it can be concluded that the incorporated margin of 2 on through-wall detectable crack length (against failure) and the current (total) safety margin of 10 on leak rate and leak detection capability are adequate for LBB application since the following maximum reduction factors were evaluated from considering the uncertainties:

- factor of 1.6 on critical crack length including a factor of 1.4 on material properties;
- factor of 3.2 on leakage crack size including a factor of 2.0 on crack morphology parameters and a factor of 1.3 on area-of-crack-opening model.

7 EXPERIMENTAL VALIDATION OF LBB BY LARGE SCALE TESTING (TASK 5)

Deliverables 11, 12, 16 [36,37] and a total of 7 reports originated from Task 5. The general conclusions concerning the work in Task 5 were as follows:

- The previously performed about twenty structural tests have been well enough documented to enable planning of a test which filled a gap in the previous test programmes and provided additional experimental validation of the leak before break behaviour of the RBMK main coolant circuit large diameter piping.
- The test addressed several issues not covered in the previous relevant test programmes. The main ones were:
  - Through wall crack,
  - Circumferential crack in a circumferential site weld,
  - Combined internal pressure and bending moment loading, and
  - Cyclic loading phase prior to the static fracture test.
- A valuable test was successfully conducted. Ductile failure occurred at an ambient temperature of 12 degrees C. A similar form of failure would therefore also be expected at elevated operating temperature, with possibly further enhanced toughness, and with no less significant plastic deformation and crack opening, which would be expected to be conducive to large, easily detected leakage flows.
- The experiment demonstrated enhanced toughness due to tearing by a factor of at least 1.5 on the initiation load
- The internal pressure of 100 bar applied to produce specimen failure was a factor of 2 larger than the level for Normal Operation Conditions.
- Any future structural testing programmes on the ϕ800 mm RBMK pipelines should only be planned on the basis of inadequate margins for LBB being obtained from a calculated assessment.

The information available on previous large scale tests was presented [38] and reviewed [39] to understand the relevance of this information and how it influences the requirements for an additional large scale structural test of a piping component to be carried out in this project. A carefully considered test program [40] was produced to help ensure a successful and valid outcome for the test. Preliminary fracture mechanics analyses were performed [41] to support decisions on the exact loading sequence.

Although very demanding both technically and economically an actual pipe section of the ϕ800 mm and 3 m in length with central site girth weld was tested [42].

After multiple phases of processing, the crack was sealed for internal pressure, the test sample was carefully instrumented and a combined loading was introduced through the internal hydrostatic pressure together with the external tension and bending loading realised by a 20MN hydraulic actuator.

Before the final phases of monotonic loading, the crack had grown to a length of 705 mm by fatigue loading. The impressive test arrangement was demonstrated on site to EU experts.

8 IN-SERVICE INSPECTION (TASK 6)

Deliverables 13, 14 [43,44] and a total of 7 reports originated from Task 6 dealing with the In-service inspection aspects of this project. The Task is further sub-divided into Task 6.1 steps 1 to 3, Task 6.2 steps 1 to 5 and Task 6.3 step 1. The general conclusions concerning the work in Task 6 were as follows:

- The 16 inspection maps provided were well documented and they have been reviewed in detail. [45,46,43,44]

- Automated inspection systems are used wherever possible on the MCC piping to improve the effectiveness of the inspection. This should also provide the additional benefits of reducing dosage to inspectors and improving the standards of records kept of inspections. [47,44]

- Further work should be carried out to establish the effectiveness of automated inspection systems, techniques and procedures developed specifically for RBMK plant inspection. This work should also accommodate the assessment of the effectiveness of operator training in the use of this equipment and the inspection procedures.

- The test conditions and in particular the defect populations associated with the practical trials of the two automated systems tested were different. It follows that the difference in the performance exhibited may not be significant.

- Further work should be carried out to supply of automated and semi-automated in-service inspection equipment for ultrasonic inspection of large diameter MCC piping.

Task 6.1 resulted in comments on the effectiveness of the Russian manual inspection of the MCC piping as presented in deliverable 13 of the VTT work plan. Some deficiencies of coverage were identified and communicated to RDIPE. [43]

The current effectiveness of manual UT inspection for detection of defects was evaluated in Task 6.2. Two advanced sizing systems were evaluated as part of Task 6.2, the AUGUR 4.2 system and the SUMIAD/MASERA system. The evaluation of the AUGUR system was based upon previous blind trial work carried out at AEA Technology's Risley establishment. The evaluation of the SUMIAD/MASERA system was carried out at VTT's establishment at Espoo. [48,49,50]

9 LEAK DETECTION AND CONDITION MONITORING SYSTEMS (TASK 7)

Deliverable 15 [51] and a total of 4 reports originated from Task 7. The general conclusions concerning the work in Task 7 were as follows:

- For leak detection of the ϕ800 mm pipelines and the suction header (as well as the lower parts of the downcomers) the implementation of the Moisture Leakage Detection System with Sensor Tube (FLUES) is highly recommended (high sensitivity: < 1 kg/h, reasonable response time: 15 min, easy to implement even in older plants)

- From the remaining leak detection systems regarded in the project the following can be recommended for implementation in RBMKs (ϕ800 mm pipeline monitoring):
  - Humidity monitoring (also in combination with monitoring of the water inventory in the containment air)
  - Radioparticulate activity monitoring
  - Acoustic leakage monitoring
  - Radiogas activity monitoring

- A combination of different monitoring parameters (acoustic noise, humidity, radioparticulate activity) should be applied and optimised to meet the requirements of LBB concept at RBMK units.

- Condition monitoring systems with "on-line" data acquisition should be implemented for the whole RBMK reactor installation. Vibration monitoring (first of all for rotating machinery especially the main circulation pumps), water chemistry monitoring and fatigue monitoring should be performed. The recommendations for the implementation of these systems came from general consideration of nuclear and operational safety aspects of the whole RBMK (urgent requirements for condition monitoring only for the ϕ800 mm pipelines do not exist), but need to be analysed on plant specific basis.

- In Russia the regulatory documents do not contain frame conditions and requirements for automated load and fatigue monitoring for components of VVER and RBMK NPPs. This may make the implementation of these systems more difficult at present. That is why it is highly recommended to supplement the existing guidelines, standards and regulations in Russia with new requirements for automated data acquisition for condition monitoring systems in NPPs. These documents should be comparable to them existing in Western Europe (Germany, France), U.S. and Japan.

During the presentation of leak detection systems several systems were regarded and analysed in more details [52]. During the project on site experiments were performed with equipment developed by Russian manufacturers. At Siemens laboratories in Erlangen the moisture leakage detection system with sensor tube FLUES was demonstrated and tested in detail. The leak detection system LDS and the acoustic leak monitoring system ALUES were discussed and the results obtained during the implementation of these systems in PWR were analysed. [53]

The results provide the technical possibilities of these systems for leak detection, leak location, and estimation of leak rate.

The state of the art of Condition monitoring at the reference RBMK (Smolensk-3) was presented and the requirements for such systems were analysed [54]. A fatigue monitoring system like FAMOS will not only satisfy such code requirements but will also establish the database to decide on NDE frequencies, component maintenance, repair, replacement or lifetime extension. Thus, the safe and economic operation of the nuclear installation will be enhanced. The application of FAMOS at VVER was analysed and demonstrated in other Tacis projects [55].

10 EVALUATION OF LEAK BEFORE BREAK SAFETY CASE (TASK 8)

Deliverable 17 [56] and a total of 3 reports originated from Task 8. The conclusions were as follows:

- The reported results indicate that LBB behaviour could be satisfactorily demonstrated for the Smolensk 3 ϕ800 mm main coolant piping.

- There is a potential for utilisation of the LBB concept for other components and pipelines in the Smolensk-3 reactor and also in other RBMK reactors. The Russian experts engaged in this project should play a leading role in undertaking such work.

A final updated version (revision 4) of the compiled glossary was published. It is sufficient for the aims of the current project and an agreement on the meaning of the terms was reached between the parties. The Russian language counterparts of the terms are included in the glossary. [57]

See Chapters 11 and 12 for a summary and recommendations concerning the whole project.

11 SUMMARY

The project has been completed as specified in the Technical Terms of Reference (TOR) of the project. All the deliverables specified in the TOR were prepared and the objectives of the project were successfully accomplished.

A complete deterministic evaluation of the leak before break safety concept was performed for the large diameter (ϕ800 mm) main coolant circuit (MCC) piping of the selected Reference Unit, Smolensk-3. The LBB concept is considered applicable for this studied case.

The European (German) LBB procedure was chosen as the methodology to be applied and evaluated for use in the reference case for a RBMK 1000 unit. The US NUREG 1061 methodology was used only for comparison.

All the structural materials used for large diameter MCC piping fabrication are ductile at operational temperature ranges. The results indicate that materials show ductile behaviour throughout the operational temperature range, and that the mechanical properties meet the requirements defined by the specifications set in the relevant Russian regulations. Comparison of RDIPE and Siemens results on fracture resistance J-R-curves showed that the results are consistent and within a common scatter band.

Environmentally assisted cracking is considered to be very unlikely. This is confirmed by operational experience of all the RBMK plant units. However, it would be of interest to confirm whether stress corrosion cracking or corrosion fatigue could be possible in unexpected adverse combinations of metallurgical structure of materials, water chemistry and loading conditions.

The LBB analysis showed adequate margins for the studied component, on crack size and leak rate for the actual plant piping materials. This conclusion was supported by the results of fracture mechanics, thermal-hydraulic and leak rate analyses. The adequacy of the incorporated current margin of 2 on through-wall detectable crack length (against failure) and the current (total) margin of 10 on leak rate and leak detection capability were evaluated by considering the uncertainties. A residual margin of 1.3 remains to account for additional uncertainties in estimates of maximum load-carrying capacity of the cracked pipes, and a reserve margin of 3.1 remains to account for additional factors and uncertainties affecting leak rate.

A major effort was expended on a structural validation test the loading conditions of which were more severe than those experienced in the plant under normal operation. The results obtained demonstrated LBB behaviour for the actual Smolensk 3 main circulation pump (MCP) piping with sufficient safety margins in relation to fatigue crack growth, crack initiation and catastrophic failure. In fact the experiment demonstrated enhanced toughness due to tearing by a factor of at least 1.5 on the initiation load. This experiment provided additional validation information to that obtained from many (about 20) structural tests previously carried out in Russia on the ϕ800 mm RBMK piping materials.

The inspection maps provided were well documented and automated inspection systems are used wherever possible on the MCC piping. Comparison of the Western and Russian automated defect detection and sizing capabilities showed relatively good compliance. Urgent delivery of appropriate inspection equipment for ϕ800 mm piping in the Smolensk NPP Unit 3 and all other RBMK units is recommended. Further work should be carried out to establish the effectiveness of automated inspection systems, techniques and procedures for all other RBMK components.

For leak detection of the ϕ800 mm pipelines and the section header as well as the lower parts of the downcomer, the following leak detection systems are recommended:

- Humidity monitoring (also in combination with monitoring of the water inventory in the containment air),
- Radioparticulate activity monitoring and Radiogas activity monitoring, and
- Moisture Leakage Detection System with Sensor Tube (FLUES).

Another important aspect of the project was to exchange knowledge between the EU and Russian experts and organisations. The expertise and motivation of the Local Subcontractor’s (RDIPE) team is very good. It is clear that the local team forms a remarkable asset in maintaining confidence to the LBB behaviour of RBMK reactors.

12 MAJOR RECOMMENDATIONS

The following major recommendations can be made on the basis of the results of the project:

1. The project resulted in the conclusion that LBB safety concept is applicable and, based on the input data and assumptions made, the LBB safety concept was fulfilled for the studied ϕ800 mm piping of Smolensk NPP Unit 3. However in order to fully confirm the statement, implementation of leak detection systems should be undertaken for ϕ800 mm pipelines and other MCC components with diameters more than 300 mm in the same compartment.

2. LBB analyses should be performed for other piping components (with outer diameter more than 300 mm) in Smolensk NPP Unit 3.

3. LBB analyses for ϕ800 mm pipelines should be performed for other RBMK units. When undertaking this, it is important that plant and unit specific analyses are performed and that the results obtained in the current project are not just transferred. In particular, the evaluation of the applicability of the LBB safety concept also to the first generation RBMK plants is highly recommended, because the design concept of the first generation of RBMK plants assumed that for these NPP units the Double End Guillotine Break (DEGB) of MCP piping is beyond Design Basis Accident.

4. The Local Team, which was led by RDIPE, is considered a valuable asset for ensuring and enhancing nuclear safety in Russia, and should therefore be kept active in the relevant technological area by all possible means available.

REFERENCES

1. J. Solin. Deliverables 1&2, Project plans, methodology and conditions for LBB concept applicability evaluation (Task 1.1 - 1.2 of Tacis NUCRUS 94231 project, VTT report No. 13). VTT Manufacturing Technology, Espoo 1997, 3 pages.
2. J. Solin. Deliverable 3, Report describing reference unit and selected features (Task 1.3 - 1.4 of Tacis NUCRUS 94231 project, VTT report No. 18). VTT Manufacturing Technology, Espoo 1997, 8 pages.
3. J. Solin. Deliverable 4, Glossary of terms (Task 1.5 of Tacis NUCRUS 94231 project, VTT report No. 17). VTT Manufacturing Technology, Espoo 1997, 2 pages.
4. J. Solin. Deliverable 18, Progress and Completion reports (Task 1.6 of Tacis NUCRUS 94231 project, VTT report No. 28). VTT Manufacturing Technology, Espoo 1997.
5. J. Solin & E. Brylev (signers). Inception Report to Tacis NUCRUS 94231, Leak Before Break Concept Applicability Evaluation (RBMK Reactors), dated 4.11.1996, 7 pages + app.
6. VTT Manufacturing Technology. Detailed Work Plan for Tacis NUCRUS 94231 Project on LBB Concept for RBMK Reactor. CEC Contract WW.94.06/01.02/B009, Espoo, June 1996, 25 pages.
7. V. Kiselyov. Statement of methodology and conditions for leak before break concept applicability evaluation (RBMK reactors) (Task 1.2 of Tacis NUCRUS 94231 project, RDIPE report No 1, Revision 1, dated 13.09.1996). RDIPE report no. 23.5823, Moscow 1996, 18 pages.
8. G. Bartholomé. Leak-Before-Break-Assessment of pressurized components, part I: description of German LBB-procedures, practices and applications including leakage detection system capabilities. Siemens KWU report KWU NT 13/96/E046, Erlangen 1996, 25 pages.
9. G. Saprykin, R. Umjarov, A. Petrov & A. Arjaev. Supply of basic design data (Task 1.3 of Tacis NUCRUS 94231 project, RDIPE report No 2, Revision 1, dated 15.09.1996). RDIPE report no. 4.2280T, Moscow 1996, 45 pages.
10. L. Gardner. Tacis NUCRUS 94231: reference unit and structural features, AEA Technology plc report AEAT-1135, dated 8.1.1997. Risley 1997. 5 pages + app.
11. V. Kiselyov, L. Babkin, E. Rivkin, V. Belous & A. Zeygarnik. Evaluation of integrity and operation history of RBMK large diameter primary circuit piping (Tasks 2.1,3.1,3.2 of Tacis NUCRUS 94231 project, RDIPE report No 5, Revision 1, dated 15.01.1997). RDIPE report no. 23.5909, Moscow 1997, 61 pages.
12. V. Kiselyov, E. Rivkin, B. Strelkov & A. Arjaev. Glossary of terms (Task 1.5 of Tacis NUCRUS 94231 project, RDIPE report No 3, Revision 2, dated 15.09.1996). RDIPE report no. 23.5824R, Moscow 1996, 22 pages.
13. L. Gardner. Tacis NUCRUS 94231: Review of LBB glossary of terms (Task 1.5 of Tacis NUCRUS 94231 project, AEAT report No. 2). AEA Technology plc report no AEAT-1136, Risley 1997, 18 pages.
14. T. Saario. Deliverable 5, Report describing materials and fabrication (Task 2.1 of Tacis NUCRUS 94231 project, VTT report No. 16). VTT Manufacturing Technology, Espoo 1997, 3 pages.

15. T. Saario. Deliverable 6, Material properties database (Task 2.2 of Tacis NUCRUS 94231 project, VTT report No. 15). VTT Manufacturing Technology, Espoo 1997, 3 pages.

16. T. Saario. Deliverable 10, Material properties assessment (Task 2 of Tacis NUCRUS 94231 project, VTT report No. 25). VTT Manufacturing Technology VALC486, Espoo 1998, 9 pages.

17. L. Babkin, T. Osipova & L. Repina. Compilation of materials properties database (Task 2.2 of Tacis NUCRUS 94231 project, VNIIAES/RDIPE report No 12, Revision 1, dated 15.05.1997). VNIIAES report no. OE/912.0597, Moscow 1997, 370 pages.

18. V. Kiselyov, A. Popov & E. Parshutin. Programme of materials testing (Task 2.3 of Tacis NUCRUS 94231 project, RDIPE report No 7, Revision 1, dated 15.01.1997). RDIPE report no. 23.5905, Moscow 1997, 16 pages.

19. A. Popov & E. Parshutin. Testing results of MCP piping archive materials of Smolensk NPP Unit 3 (Task 2.3 of Tacis NUCRUS 94231 project, RDIPE report No 15, Revision 1, dated 21.09.1997). RDIPE/ENES Report no. 23.6072, Moscow 1997, 140 pages.

20. H. Schendzielorz. Fracture mechanics and drop weight tests of main circulation piping archive material of Smolensk NPP Unit 3, Siemens KWU report KWU NT 12/98/E007, dated 16.02.1998, Erlangen 1998, 29 pages.

21. D. Worswick, Peter Hurst. Deliverable 7, Report on operating history, leakage problems and defects (Task 3.3 of Tacis NUCRUS 94231 project, AEAT report No. 10). AEA Technology plc, Risley 1997, 3 pages.

22. D. Worswick. Tacis NUCRUS 94231 project LBB Concept Evaluation (RBMK Reactors): Initial AEA approach to agree specification for task 3 (Task 3.1 of Tacis NUCRUS 94231 project, AEAT report No. 1). AEA Technology plc, Risley 1996, 7 pages.

23. D. Worswick & P. Hurst. Evaluation of integrity and operational history of RBMK large diameter primary circuit piping (Task 3.3 of Tacis NUCRUS 94231 project, AEAT report No. 8), AEA Technology plc report AEAT-2097, Risley 1997, 37 pages.

24. H. Keinänen. Deliverable 8, Review of the existing technical analyses with specifications for new analyses (Task 4.1 of Tacis NUCRUS 94231 project, VTT report No. 14). VTT Manufacturing Technology, Espoo 1997, 4 pages.

25. H. Keinänen. Deliverable 9, Technical analyses (Task 4 of Tacis NUCRUS 94231 project, VTT report No. 24). VTT Manufacturing Technology, Espoo 1998, 15 pages.

26. NRC Pipe Break Task Group, Evaluation of Potential for Pipe Breaks, NUREG-1061, Vol.3, Washington, D.C, November 1984.

27. V. Kiselyov, E. Rivkin, A. Arjaev, I. Baranov, V. Tkachev & V. Aladinsky. Results of existing technical analyses for RBMK main circulation circuit piping (Task 4.1 of Tacis NUCRUS 94231 project, report No. 6, Revision 1, dated 15.01.1997). RDIPE report no. 23.5910, Moscow 1997, 76 pages.

28. A. Arjaev, Y. Smirnov, Y. Golovlev, V. Tkachev, M. Osokin & M. Malov. Results of Stress Analysis for Smolensk NPP Unit 3 Main Circulation Circuit Piping. (Task 4.2 of Tacis NUCRUS 94231 Project, RDIPE report No. 13, Revision 1, dated 26.05.1997). RDIPE Report no.23.5957, Moscow 1997, 154 pages.

29. A. Arjaev, Yu. Smirnov, & V. Tkachev. Analysis of stresses in longitudinal welds of Smolensk NPP unit 3 MCP pipe bends (Task 4.2 of Tacis NUCRUS 94231 project,

RDIPE report No. 14, Revision 1, dated 26.06.1997). RDIPE report no. 23.5982, Moscow 1997, 62 pages.

30. V. Kiselyov & M. Dobrov. Fracture Mechanics Analysis of Large Diameter MCP Piping. (Task 4.3 of Tacis NUCRUS 94231 Project, RDIPE report No. 18, Revision 1, dated 22.09.1997). RDIPE/ENES Report no.23.6073, Moscow 1997, 65 pages.

31. V. Tkachev & K. Zheltukhin. Three dimensional finite element fracture mechanics analysis of large diameter pipe elbow for Smolensk 3 unit (Task 4.3 of Tacis NUCRUS 94231 project, RDIPE report No. 19, Revision 2, dated 24.11.1997). RRC "Kurchatov Institute" report no. 33-05/36. RRC "Kurchatov Institute" / ENES, Moscow 1997, 15 pages.

32. D. D. Paul, N. Ghadiali, S. Rahman, P. Krishnaswamy & G. Wilkowski. SQUIRT Computer Code. Version 2.3. Battelle, Columbus, November 1994.

33. K. Ikonen & H. Raiko. LBB assessment of the weld 21-5 (Task 4.4 of Tacis NUCRUS 94231 project, VTT report No. 21). Updated Research report ENE4/08/98. VTT Energy, Espoo 1998, 18 p. + app. 16 pages.

34. K. Ikonen & H. Raiko. Memorandum 1998.05.04 (Task 4.4 of Tacis NUCRUS 94231 project, VTT report No. 23). VTT Energy, Espoo 1998. This memorandum is related to reference [33], 4 pages.

35. V. Kiselyov, V. Tkachev, E. Rivkin & M. Dobrov. Leak before break evaluation for large diameter MCP piping (Task 4.4 and 4.5 of Tacis NUCRUS 94231 project, RDIPE report No. 20, Revision 2, dated 15.01.1998). RDIPE/ENES report no. 23.6115, Moscow 1997, 53 pages + app. 20 pages.

36. L. Gardner. Deliverables 11 & 12, Review and specifications for structural testing (Tasks 5.1-5.2 of Tacis NUCRUS 94231 project, AEAT report No. 9). AEA Technology plc, Risley 1997, 3 pages.

37. L. Gardner. Deliverable 16, Tacis NUCRUS 94231: Review of LBB Validation Test (Task 5.4 of Tacis NUCRUS 94231 project, AEAT report No. 14). AEA Technology plc AEAT-3684, Risley 1998, 12 pages.

38. V. Kiselyov, E. Rivkin & A. Sudakov. Review of previous large scale tests of RBMK main circulation circuit piping components (Task 5.1 of Tacis NUCRUS 94231 project, RDIPE report No 4, Revision 1, dated 20.11.1996). RDIPE report no. 23.5856, Moscow 1996, 33 pages.

39. L. Gardner. Tacis NUCRUS 94231: Requirements for LBB validation test (Task 5.2 of Tacis NUCRUS 94231 project, AEAT report No. 7). AEA Technology report AEAT-1810, Risley 1997, 10 pages.

40. V. Kiselyov & A. Sudakov. Programme of structural test (Task 5.2 of Tacis NUCRUS 94231 project, RDIPE report No 10, Revision 3, dated 19.05.1997). RDIPE report no. 23.5952. Moscow 1997, 16 pages.

41. V. Kiselyov. Preliminary fracture mechanics analysis of cracked full size straight pipe for structural testing (Task 5.2 of Tacis NUCRUS 94231 project, RDIPE report No 11, Revision 1, dated 5.05.1997). RDIPE report no. 23.5953, Moscow 1997, 53 pages.

42. V. Kiselyov & A. Sudakov. Structural test of actual Smolensk 3 MCP straight pipe (Task 5.3 of Tacis NUCRUS 94231 project, RDIPE report No. 22, Revision 1, dated 03.06.1998). RDIPE report no. 23.6114, Moscow 1998, 20 pages + 35 figures.

43. P. Conroy. Deliverable 13, In-service inspection maps (Task 6.1 of Tacis NUCRUS 94231 project, AEAT report No. 11). AEA Technology plc, Risley 1997, 11 pages.

44. P. Conroy. Deliverable 14, Report on Task 6 of Tacis NUCRUS 94231 Leak Before Break Project (Task 6.3 of Tacis NUCRUS 94231 project, AEAT report No. 13). AEA Technology plc AEAT-3664 / IVCR9800023, Risley 1998, 8 pages + app. 22 pages.

45. B. Strelkov, A. Aref'ev, N. Timofejev, V. Anisimova & Y. Lobanov. Production of inspection maps (Task 6.1 of Tacis NUCRUS 94231 project, RDIPE report No 9, Revision 2, dated 15.01.1997). RDIPE report no. 840.04, Moscow 1997, 104 pages.

46. S. Smalley. Practical Investigation of RDIPE UT Inspection Techniques as Specified in Report No 840.04 (Task 6.2 of Tacis NUCRUS 94231 project, AEAT report No. 5). AEAT - 1505 / IVCR1485 Issue A, Risley 1997, 4 pages.

47. B. Strelkov, A. Aref'ev, N. Timofejev, V. Anisimova, V. Badalian, & D. Tikhonov. Demonstration of upgraded inspection performance (Task 6.2 of Tacis NUCRUS 94231 project, RDIPE report No. 16 Revision 1, dated 15.07.1997). RDIPE report no. 840.11, Moscow 1997, 135 pages.

48. C. Bostock & P. Conroy. Test Piece Design Specification for the Performance Evaluation Trials of Tacis NUCRUS 94231 Leak Before Break Project (Task 6.2 of Tacis NUCRUS 94231 project, AEAT report No. 4). AEAT -1497 / IVCS266 Issue A, Risley 1997, 5 pages + app. 8 pages.

49. P. Conroy. Specification for the Performance Demonstration Component of Tacis NUCRUS 94231 Leak Before Break Project (Task 6.2 of Tacis NUCRUS 94231 project, AEAT report No. 12). AEAT - 2710 / IVCS9700297 Issue A, Risley 1997, 6 pages.

50. P. Conroy. Report on the Defect Sizing Validation Trials of the RDIPE Inspectors and the AUGUR 4.2 Inspection System. IVCR1448 Issue A, Risley 1996.

51. U. Kunze. Deliverable 15, Report on adequacy of leak detection and condition monitoring systems for LBB and recommendation for their improvement (Task 7.4 of Tacis NUCRUS 94231 project, Siemens report No. 5). Siemens KWU, Erlangen 1998, 9 pages.

52. B. Strelkov & Y. Korolev. Review of existing system for leak detection at RBMK plant (Task 7.1 of Tacis NUCRUS 94231 project, RDIPE report No 8, Revision 1, dated 15.01.1997). RDIPE report no. 840.03, Moscow 1997, 71 pages.

53. B. Strelkov, Y. Korolev, V. Ovchinnikov & A. Burlakov. Demonstration of upgraded leak detection systems (Task 7.2 of Tacis NUCRUS 94231 project, RDIPE report No 17, Revision 2, dated 23.12.1997). RDIPE report no. 840.17, Moscow 1997, 69 pages.

54. B. Strelkov, S. Bougaenko, Y. Korolev, A. Arjaev, V. Belous & G. Saprykin. Condition monitoring system. Demonstration of key elements in the framework of LBB application to MCP piping of Smolensk NPP Unit 3 (Task 7.3 of Tacis NUCRUS 94231 project, RDIPE report No 21, Revision 1, dated 15.01.1998). RDIPE report no. 840.30, Moscow 1998, 59 pages.

55. Final reports of the Tacis Project 3.4/91 and Tacis Project 2.11/94 “Development of Residual Lifetime Diagnostic Systems”.

56. J. Solin & H. Keinänen. Deliverable 17, Final report on the LBB case with recommendations (Task 8 of Tacis NUCRUS 94231 project, VTT report No. 26). VTT Manufacturing Technology, Espoo 1998, 33 pages.

57. V. Kiselyov. Glossary of terms (updated version) (Task 8.3 of Tacis NUCRUS 94231 project, RDIPE report No 23, Revision 1, dated 02.06.1998). RDIPE report no. 23.5824R, Moscow 1998, 22 pages.