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TACIS PROJECT R8.01/97
TRANSLATION, EDITING AND DIFFUSION OF DOCUMENTS
(Results Dissemination)

TACIS R1.2/91 and R2.16/93 Projects
PRIMARY CIRCUIT INTEGRITY: APPLICATION OF LBB CONCEPT FOR VVER 440/230 NOVOVORONESH 3 AND 4, KOLA 1 AND 2
EXECUTIVE SUMMARY

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Summary

Within the EC-program “TACIS 91 Nuclear Safety" the Consortium EDF-FRAMATOME-SIEMENS/KWU was subcontracted with the work on “Primary Circuit Integrity: Application of Leak-before-Break Concept".

The objective was to study whether the LBB-concept may be applied to the main coolant line (MCL) and the surgelines (SL) of the Russian NPP of VVER 440 - 230 type Novovoronesh 3, 4 and Kola 1, 2.

Summarizing the various stress analyses and the deterministic fracture mechanics analyses, the following conclusions can be drawn:
- Keeping in mind all the assumptions and approximations concerning data, the LBB-behavior of MCL and SL cannot be proven for the as-built situation of Novovoronesh 3, 4 (without any additional hydraulic shock absorbers to suppress seismic movements). Taking into account optimized additional seismic supports and assuming the SL to the top of the pressurizer as being cut, the LBB-behavior can be shown.
- Assuming a relevant accidental load (instead of earthquake, because of low level of seismicity), the LBB-behavior can be proven for the as-built situation of Kola Units 1, 2.

The analysis of the acoustic leakage monitoring systems (ALMS) installed at Novovoronesh 3, 4 and Kola 1, 2 show:
- The sensitivity of ALMS ensures that stable leaks can be detected long before critical dimensions are reached.
- The ALMS of Novovoronesh and Kola has to be improved (especially for the SL).

Recommendations for further activities are provided (e.g. clarification of real level of seismicity, re-evaluation of different leakage detection systems, optimization of seismic supports). These activities were realized in frame of TACIS 2.16/93 project, which was the continuation of TACIS 91 project 1.2. Within the project Siemens KWU was subcontracted with the work on "Primary Circuit Integrity Application to Leak before Break".
The aim of TACIS 2.16/93 was to give answers to the conclusions and recommendations, which have been formulated in the final Summary Report of TACIS 91, 1.2, mainly:
- Considering of real seismic behavior of Novovoronesh 3,4
- Defining and optimizing of seismic supports
LBB calculations in the frame of TACIS 2.16/93 according to US-procedures (NUREG-1061) show that introducing additional seismic supports the criteria of LBB-behavior can be fulfilled also at Novovoronesh 3 and 4.

As conclusions the present status of work on LBB-concept application to the VVER-440 (V-179/230) is performed.

Project participants:

TACIS 1.2/91

Beneficiary	«Rosenergoatom» utility
Project participants on the part of CEC	Consortium: Siemens/KWU EDF, Framatome
Subcontractor	MOHT-OTJIG RM VNIIAES Gidropress

TACIS 2.16/93

Beneficiary	«Rosenergoatom» utility
Project participants on the part of CEC	Consortium: Siemens/KWU
Subcontractor	AO “Atomenergoexport” VNIIAES
Involved party	NRI-Rez (Czech)

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INTRODUCTION

The first generation of VVER-440/B-230 plants (Novovoronezh NPP Units 3 and 4 and Kola NPP Units 1 and 2) was designed in late sixties on the basis of Codes and Standards existing at that time and meeting the safety requirements of that period.

On the basis of accumulated operation experience and analysis of the causes and consequences of emergencies at NPPs the safety requirements were significantly changed.

For this reason, to ensure NPP safe operation IAEA has launched the initiative to perform a comprehensive safety analysis of NPPs of all generations. The methodology of IAEA experts applied to VVER-440/V-230 NPPs was taken as a basis for this work. As the basis for identification of deficiencies and deviations from the requirements of modern regulatory documentation for the first generation units the conventional safety specifications such as Codes, guidelines and recommendations of IAEA, NUSS and INSAG were taken.

The Leak Before Break (LBB) concept was originally developed and applied at PWR plants in the USA to eliminate the need for special consideration of dynamic effects involving large breaks of the primary circuit piping. The basis of LBB concept consists in the demonstration of the fact that prior to the double-ended guillotine break of a certain pipeline a sufficiently large leak develops that can be reliably detected by the normal leak detection hardware existing at the plant. This is achieved by means of a quantitative determination and assessment of the loss of integrity process and of associated leaks. Implementation of LBB concept requires installation of several independent leak detection systems while requalifying the already existing systems. In addition to the aspects associated with unit scram it is necessary to assure measures to meet LBB concept conditions for all operation stages (reliable and valid inspection, maintenance, monitoring of aging, periodic examination). A primary circuit pipeline that meets LBB concept requirements can be basically considered as having a very low probability of a large-break LOCA, i.e. about 10^{-6} per reactor-year.

As early as in 1981 the US Nuclear Regulatory Commission developed a regulatory document on the application of LBB concept for high energy NPP systems with temperatures > 93^0C and pressures > 1.9 MPa. LBB application procedure adopted in this document laid the basis for assessing the possibility of applying this concept for VVER-440 plants.

1 Objectives

The objective was to study whether the LBB-concept may be applied to the main coolant line (MCL) and the surgelines (SL) of the Russian NPP of VVER 440 – 179/230 type Novovoronesh 3, 4 and Kola 1, 2.

Figure 1 presents the general outlay of one circulation loop of VVER-440/230 reactor installation. Schematic of Analysis and Calculations of Components for Compliance with the LBB Concept Requirements is shown in Fig. 2.

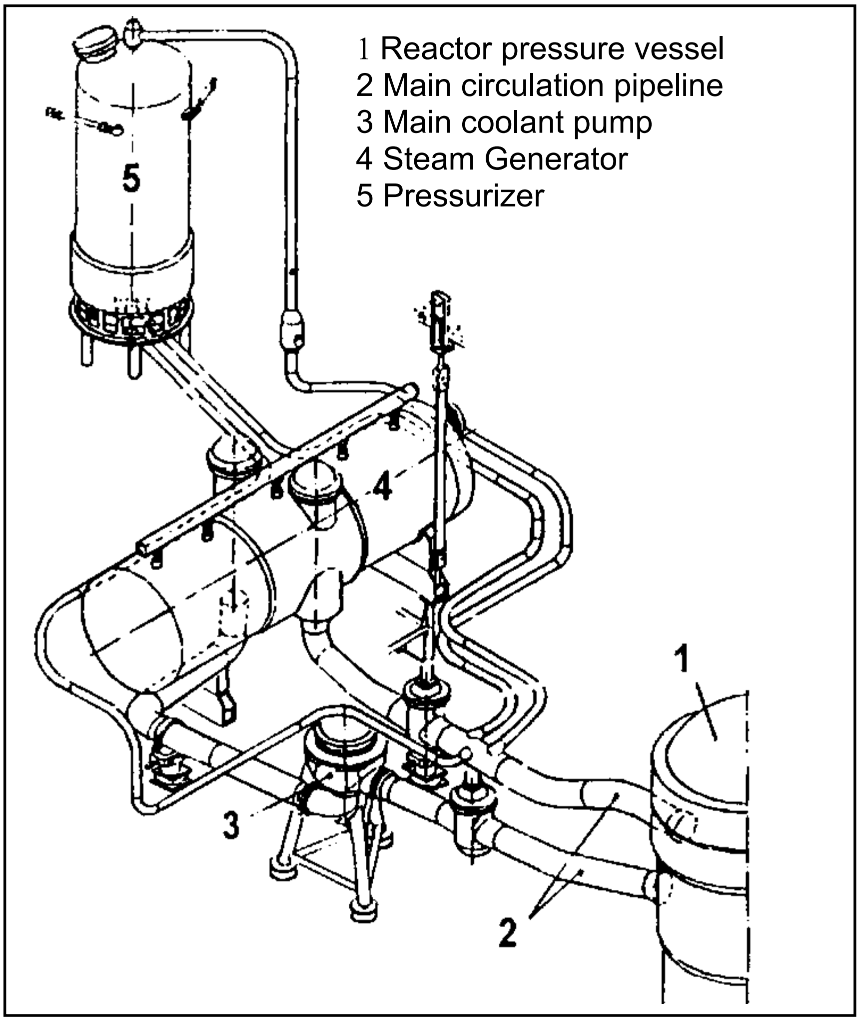

Fig.1. General Outlay of VVER-440 Major Equipment and Primary Circuit Piping

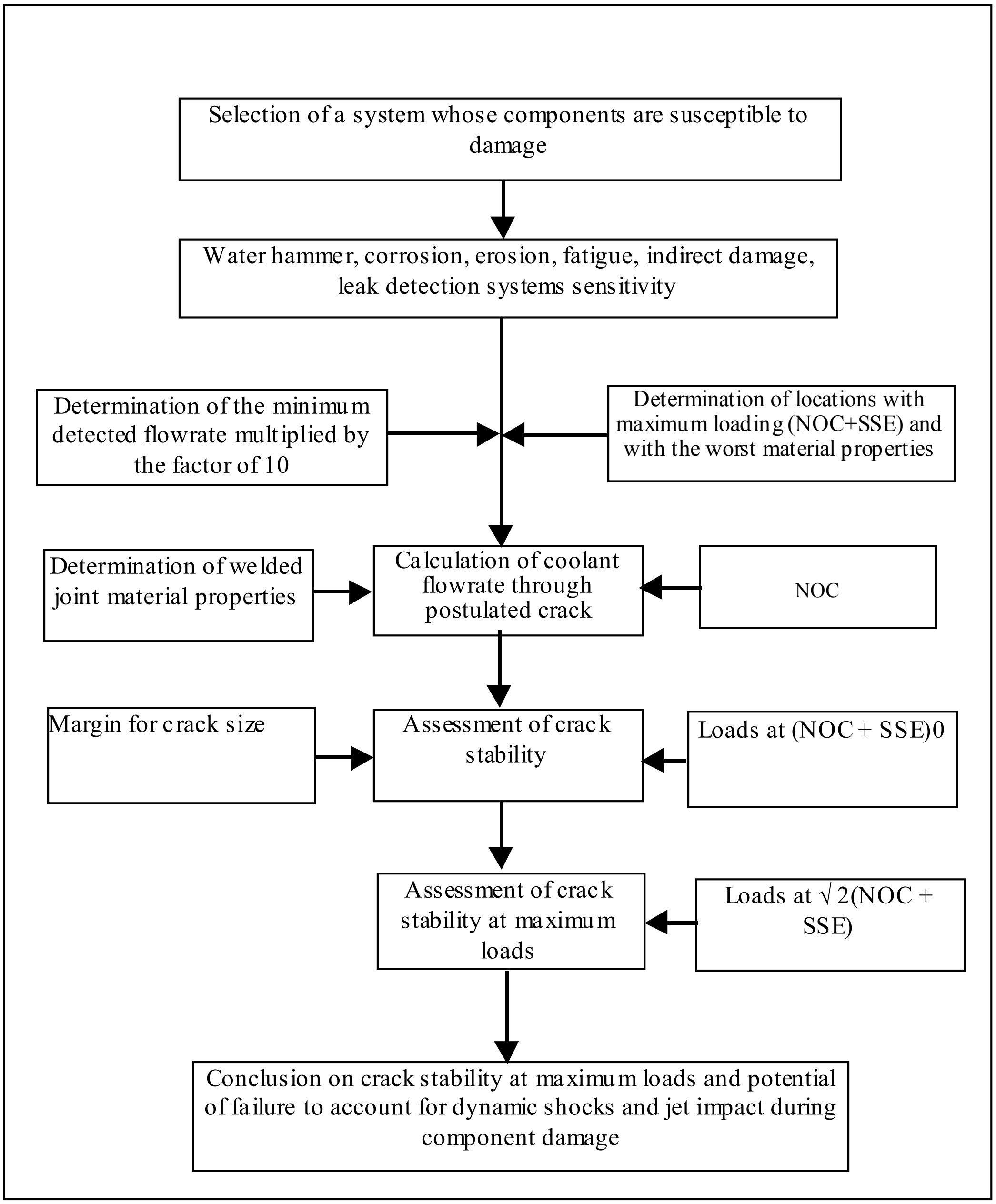

Fig.2. Diagram of Analysis and Calculations of Components for Compliance with the LBB Concept Requirements.

The work was performed in the scope of the requirements defined in the "Terms of Reference" (TOR) and was based on a Western LBB approach such as Regulatory Guide 1.45, NUREG-1061, SRP 3.6.3, IAEA Tecdoc 720 and 774 etc.

Also, in course with the project logic the document "Technical Requirements to the Application of the 'Leak Before Break' Concept for Piping of NPPs in Operation" was developed by VNIIAES, Design Bureau (OKB) "Gidropress", Scientific Technical Center of "Gosatomnadzor" (Regulatory Body of Russia), NIKIET and authorized for application by "Gosatomnadzor" of Russia (hereafter as "Technical Requirements…" M., VNIIAES, 1995). For the practical implementation of LBB concept at Russian NPP obtained within this project the requirements of "Technical Requirements…", M., VNIIAES,1995 were specially considered.

2 SUMMARY OF TACIS PROJECT 1.2/91

2.1 Scope of work

Within the EC-program “TACIS 91/Project 1.2: Primary Circuit Integrity" an LBB-analysis for Novovoronesh 3, 4 and Kola 1, 2 was performed concerning the following primary piping:

- Main coolant line (MCL) DN 500
- Surgeline (SL) DN 200.

In the frame of this project the following work was performed:

1. Analysis of actual state of piping;
2. Assessment of piping material properties;
3. Assessment of NDT methods;
4. Analysis of existed leak detection system;
5. Analysis of existed special procedures for personnel actions in case of a leak from Dnom-500 and Dnom-200 piping;
6. Numerical calculation in accordance with LBB procedure and analysis of piping reliability.

2.2 Work description

The results of experimental and calculation works were presented in 26 reports including the reports of Siemens (Germany), EDF (France), Framatome (France) prepared within the frame of this project in 1994-1995.

During work implementation the intermediate and the final outputs were reviewed by Russian and Western specialists. The experts assessed both scientific and methodological part of work and practical results.

2.2.1 <u>Analysis of actual state of piping</u>

Examinations of an actual status of Dnom 500 and Dnom 200 piping of Novovoronesh (NVV) NPP Units 3, 4 and Kola NPP Units 1, 2 were included:

- Analysis of piping conformance to the requirements of the drawings, specifications and regulatory documentation of Gosatomnadzor of Russia;
- Analysis of the certificates for metal and welded joints;
- Examination of piping walls thickness and diameters;
- Results of pre-service and in-service inspections;
- Examination of actual layouts of pipelines.

Chemical composition, micro- and macrostructure, mechanical properties, static and cyclic fracture toughness of the base metal, heat affected zone and of weld metal were evaluated also on the basis of laboratory studies of specimens cut out from the pipes after 100000 hours of operation.

The general condition of piping and metal shows that they were designed and manufactured according to the design and meet the requirements of the regulatory documentation and drawings.

2.2.2 Assessment of piping material properties

On the basis of the results of examination of the actual piping condition and on the results of non-destructive testing based on the hardness parameters not only the actual material properties were updated, but also the ageing characteristics and susceptibility to the intergranular corrosion cracking were assessed.

The assessment of fracture toughness of piping was carried out according to the M-02-92 methodology, authorized for application at NPPs by Gosatomnadzor of Russia for calculation of the acceptable flaw sizes in the metal of NPP components and piping under operation. This methodology was well proven both at NPPs and in CNIITMASH and CKTI laboratories by means of fracture tests of the full-scale specimens of Dnom500 piping elements with artificially implanted defects. Fracture toughness and crack growth characteristics of the base metal and weld metal were investigated in air at normal and high (350^{0}C) temperature and under water of high parameters. It was shown that piping materials demonstrate acceptable fracture toughness and crack growth resistance in accordance with LBB requirements.

In the frame of TACIS 91-1.2 project Framatome performed ageing tests of dissimilar welds to prove their required toughness. The performed investigation showed no change of strength properties and $J_{0.2}$ value due to the heat treatment ageing. The test results indicate acceptable toughness of the welded joints after long ageing.

2.2.3 Assessment of NDT methods which are used for piping inspection

Performed analysis has shown that the design of pipelines and compartments in which they are located allows realizing their 100% inspection. Full inspection of 100% welded joints was implemented for NVV NPP both according to "Technical Specification of MCL inspection…" specially developed during work implementation and according to the requirements of the special operation regime, introduced at Units 3, 4 NV NPP and Units 1, 2 Kola NPP from 1991. The defect detectability of non-destructive examination methods and techniques was experimentally proven using full-scale test specimens of Dnom 500 and Dnom 200 pipes contained real and artificial flaws in welded joints. These studies have shown that a possibility to miss the non-through-wall defects of critical sizes in piping is negligible.

The scope and the techniques of examination adopted at NV NPP Units 3, 4 ensure the quality of metal integrity inspection in the frame of the requirements of the LBB concept.

For further improvement of MCL reliability it is possible to recommend the replacement of radiography testing (RT) with ultrasonic testing (UT).

Recommended UT methods:

- Double-frequency method with applying of a flaw detector of ADMT-21UB model with transducer having a prism angle of 50^0 for frequencies 1.2-1.8 MHz and transducer with a prism angle of 40^0 for the same frequencies. For this method the removal of reinforcement (crown) of the welded joint is necessary.
- Inspection by longitudinal waves with a serial flaw detector such as UD2-12 or automated system like “Sumiad”. For this method the coupled transmitter-receiver inclined piezoelectric transducers of RSN-PEP type should be used.

Transducer identification	Frequency (MHz)	Angle of incidence (degree)	Focus distance (mm)	Distance to beam input point (mm)	Signal-to-noise ratio A_s/A_{noise}
P122-1,8-45-L	1.8	45	38	8	~40/18
P122-1,8-60-L	1.8	60	25	8	~46/20
P122-1,8-70-L	1.8	70	17	8	~32/8

Inspection is carried out sequentially by three transducers. The indicated transducers types have passed interdepartmental trials according to the requirements of Gosatomnadzor of Russia as part of the automated multichannel ultrasonic inspection system “Sumiad”.

The scope and the techniques of in-service examination adopted at Kola NPP Units 1, 2 and at NV NPP Units 3, 4 ensure the quality of metal integrity inspection is in conformity with the requirements of the LBB concept.

2.2.4 Analysis of existed leak detection system

The safe operation of Dnom-500 and Dnom-200 MCL at Kola NPP Units 1, 2 can be achieved by the installation at these Units of two independent leak-monitoring systems along with piping metal inspection. According to item 4.3 of the "Technical Requirements…”, M., VNIIAES,1995 the detection of leaks should be performed by using two systems.

It was shown the following:

At Kola NPP Units 1, 2 there are two leak detection systems:

1) Leak monitoring system by aerosols activity as part of “SRK Systema”;
2) Acoustic leak monitoring system “Alus”.

At NVV NPP Units 3, 4 there are three systems:

1) Leak monitoring system by aerosols activity as part of “SRK Systema”;
2) Acoustic leak monitoring system “Alus”.
3) Leak monitoring system by air the humidity in ventilation system “V-2”.

Thus in case of coolant leak in Dnom500 and Dnom200 piping via the trough-wall stable crack, this should be detected by two independent leak detection systems – by the acoustic leak detection system ALMS produced by Siemens (Germany) and by the aerosol radiation activity monitoring system in NPP compartments. For NV NPP Units 3 and 4 the leak from Dnom500 piping can be additionally detected by a third detection system: the humidity monitoring system in the plant compartments.

Taking into account the results of calculation of the minimum coolant flow rate through the cracks of the critical size and the safety margins for the leak monitoring systems sensitivity the coolant flow rate should be less than 700 l/h for D_{nom} 500 and 300 liters/hours for Dnom200 piping (considering the roughness of crack edges).

Performed calculations of sensitivity of leak monitoring facilities in hermetic compartments of Kola NPP Unit 1, 2 have shown the following:

- For radiation monitoring instrumentation - not less than 10 l/h.
- For the normal ALUS system, installed on Dnom500 piping - not less than 224 l/h for all sections of pipelines except for a MCL-SG section, where the sensitivity is equal to 505 l/h and 394 l/h for Unit 1 and 2 accordingly; for Dnom200 piping the sensitivity is 135 l/h.

The system sensitivity ensures leak detection with a sufficient margin. The existing leak detection facilities meet the requirements of the LBB concept. The fracture mechanics analysis in conjunction with leak sizes has shown that all safety margins stated in "Technical Requirements…" M., VNIIAES, 1995 are met.

During the hydro tests of the tightness (strength) of the primary circuit the ALUS system should ensure leak monitoring by all measuring channels. To prove its performance the system should be tested and calibrated by means of noise emitter according to items 4 and 9 of the "Operating instruction of ALUS-1, 2 acoustic leak detection systems (Units 1,2)" № 1,2-07-04IE-97.

In case of failure of measuring channel the efforts for unconditional recovery of their operation in the incoming NPP Unit shutdown outage should be performed but not later than 1 year after shutdown. It is recommended to update the software for processing the data obtained from the system for the purpose of system improving.

As regards radiation monitoring system hardware in hermetic compartments it has been noted that the system should be annually calibrated. Functional testing of the measuring channels of the system should also be carried out according to "Schedule of functional tests of sensors' measuring channels of radiation safety monitoring instrumentation", which is the operating procedure specific for every plant.

Repair of system channels, acceptance after repair and maintenance should be carried out according to items 5, 8, and 9 of "Operating instructions of radiation monitoring system at Units 1 and 2 №1, 2-06-09IE-95".

2.2.5 Analysis of existing special procedures for personnel actions in case of a leak from Dnom-500 and Dnom-200 piping;

The analysis of personnel procedures for elimination of small leaks and emergencies was performed at Kola NPP Units 1, 2 and at NV NPP Units 3, 4. The application of the LBB concept for these NPPs was shown to require upgrading special procedures for personnel actions in case of a leak from Dnom-500 and Dnom-200 piping.

2.2.6 Numerical calculation in accordance with LBB procedure and analysis of piping reliability

An integral criterion of correct implementation of the design and construction work as well as fabrication and operation is also the conformance of the actual static and cyclic loads level to the requirements of strength standards for NPP. It was shown that taking account of the actual loading conditions the design lifetime of piping is ensured, and the safety margins for NOC conformed to the requirements of NPP strength standards. Also, an analysis of additional specific loading was carried out and the absence of possibility of hydro hammer in the primary circuit piping was demonstrated.

At the same time the calculations of stresses under the safe shutdown earthquake (SSE), conducted for the site seismicity 7 of MSK-64 scale have exceeded an acceptable level for NVNPP Units 3, 4. To reduce the stresses under SSE it is necessary either to refine the seismicity of the site or to implement the calculation of additional snubbers locations.

The calculation results show that at NV NPP Units 3 and 4 the safe operation of MCL Dnom-500 and Dnom-200 in NOC regime can be reached by organisation of leak monitoring practice by means of available systems and by metal integrity inspection. For SSE regime it is required to carry out additional calculations taking into account the stratification phenomenon and installation of additional snubbers.

These results allow to conclude that Dnom-500, Dnom-200 Primary Circuit Piping is designed and manufactured according to the existing requirements of the regulatory documentation, the operation of piping is satisfactory and does not result in premature exhaustion of their lifetime. At the same time the assessment of piping status under SSE requires additional efforts. In connection with this, the introduction of the LBB concept at NVNPP Units 3, 4 should be implemented in two stages:

At the first stage - for NOC, at the second stage - for SSE. The work for SSE regime was carried out under TACIS 93 project R2.16/93.

A feasibility study on probability of leak in Dnom 500 and Dnom 200 piping was also carried out in frame of this project. According to the Western partners of the consortium the feasibility study showed that a quantitative probabilistic analysis could not be performed due to lack of relevant data. The absolute failure probabilities were created accordingly without specific plant data of Novovoronesh /Kola NPPs. On the basis of experimentally determined characteristics of the static and cyclic fracture toughness it was shown that through-wall cracks were stable enough and grew up to the critical sizes during a time of operation of more than 1 year.

Using actual characteristics of the defect detectability in NDT examination, the actual crack growth rates data in the piping and considering the real piping loads in operation conditions it was shown, that the reliability of the pipelines (according to the criterion of resistance to un-stable fracture) is acceptable and give a value not less than ($1 \cdot 10^{-6}$) per reactor-year.

2.3 Overview of the TACIS 1.2/91 project results

The calculation and experimental analysis of a possibility of LBB concept application to NV NPP Units 3, 4 and Kola NPP Units 1, 2 was carried out. It is shown that LBB concept can be applied to the units. The conditions were determined, at which LBB concept application with maintenance the needed reliability level of MCL in operation is ensured.

<u>I. Kola NPP Units 1, 2:</u>

1.1. The " Leak Before Break" concept is applicable for MCL in all operation conditions.

1.2. The status of leaking pipe is possible for any welded joint with the following safety margins:

- the factor of 2 – for the length of critical through-wall crack (the safety margin for the crack length ensuring crack growth to the critical size during 1 year of operation);

- the factor of 1.4 – for the loading value.

1.3. The existing leak detection systems at Kola NPP Units 1, 2 allow to monitor leaks through the stable cracks with the following safety margin n_0:

The leak monitoring system by aerosols activity $n_0 > 10$;

The acoustic leak monitoring system $n_0 > 10$.

1.4. The existing leak monitoring systems allow to detect a maximum compensable leak with a safety margin 10.

1.5. Quantitative analysis of probability of leak originating and complete break of the primary circuit piping has shown that these events essentially depend on the quality (defects detectability) of non-destructive examination and on hydro test conditions. Thus, in case of 100 % inspection by existing methods of dye penetrant and UT the probability of leak occurrence is within the range of 10^{-3} - 10^{-4} per reactor-year. The probability of a complete break of the piping is within the range of 10^{-5}-10^{-6} per reactor-year. It should be noted, however, that the input data in the probabilistic assessment was not very relevant for the Kola units as mentioned above.

1.6. To ensure piping reliability at a level of $<<10^{-6}$ per reactor-year the application of more advanced methods of ultrasonic testing is necessary including also the UT of dissimilar welds.

II. Novovoronezh NPP Units 3, 4.

2.1. The "Leak Before Break" concept can be applied for MCL in all operation conditions. However for NOC+SSE regime it is necessary to refine the SSE value. In case of confirmation site seismicity of 7 for MSK-64 scale it is necessary to install the additional snubbers and to conduct supplementary calculations in particular taking in account the stratification stresses.

2.2. A leak from the piping welded joints is possible with the following safety margins:

- the factor of 2 – for the length of critical through-wall crack (the safety margin for the crack length ensuring the crack growth to the critical size during 1 year of operation);
- the factor of 1.4 – for the loading value.

2.3. The existing leak detection systems at NV NPP Units 3, 4 allow to monitor leaks through the through-wall stable cracks (according to item 2.2) with the following safety margin (for NOC):

The leak monitoring system by aerosols activity > 10;

The acoustic leak monitoring system > 10.

The leak monitoring system by the steam humidity > 10;

2.4. The existing leak monitoring systems allow detecting maximum compensable leaks with a safety margin of 10.

2.5. Quantitative analysis of the probability of leak originating and the complete break of MCL under NOC has shown that the probability of leak occurrence is within the range of 10^{-3} - 10^{-4} per reactor-year and the probability of a complete break of the piping is within the range of 10^{-5}-10^{-6} per reactor-year. Here again it should be noted, however, that the input data in the probabilistic assessment was not very relevant for the Novovoronesh units as mentioned above.

2.6. The performance of UT with improved detection reliability makes it possible to reach the significantly higher reliability level of MCL based on the criterion of leak occurrence or pipe break.

2.4 Recommendations of TACIS 1.2/91 project

1. For Kola NPP Units 1 and 2: to proceed to actual introduction of the LBB concept. For this purpose it is necessary to foresee the development (or upgrading) of existing regulatory documentation for NPP personnel and application of UT with improved defect detectability. Special attention here should be focused on dissimilar welds inspection. The necessity to upgrade the leak monitoring systems should be determined after their examination.

2. For Novovoronezh NPP Units 3 and 4: to proceed to LBB concept application in two stages:

Stage 1 - application of LBB concept for NOC regime (similar to Kola NPP).

Stage 2 - application of LBB concept for NOC+SSE regimes. In this case the following should be provided:

- perform additional seismic loading analysis with the purpose to update the applied stresses and reduce their level;
- carry out additional strength calculations taking account of additional safety margin for the effect of the stratification on piping metal;
- improve piping integrity by applying advanced UT methods thus leading to the increase of resistance to piping break under NOC+SSE;
- install additional snubbers (in case of insufficiency of the measures listed above).

3 PROGRESS OF WORK UNDER THE PROJECT TACIS-R2.16/93

3.1 The possible directions of work

On the basis of the results of conducted work and for the purpose of its practical application, in particular for NVNPP Units 3 and 4, three possible directions of work performing were identified:

1. Straight path: Additional snubbers and pipe restrictions installation.

This requires versatile piping stress calculations with the purpose to optimize the snubbers' number, location, fabrication, analysis of plant rooms suitability (in terms of acceptable loads) plus installation work.

2. Second alternative path – to clarify seismic loading taking account of damping effect and the elastic-plastic stresses in the calculations.

In this case there is a possibility to determine an acceptable level of stresses, at which additional snubbers installation is not required.

3. Third alternative way –improvement of non-destructive examination and repair quality that will increase piping reliability under SSE up to an acceptable level.

The last way is the most cost-effective solution and allows increasing reliability not only under SSE but also in all operating conditions. However, this approach is based on the probability aspects, which are rejected by LBB concept.

To choose an optimum approach to the introduction of the TACIS project R1.2/91 results within the frame of the new TACIS project R2.16/93 the studies of additional requirements to the calculation and experimental justification of LBB concept application were performed (for example the account of the stratification phenomenon, installation of restrictions to reduce pipe whip effect and jet impingement, improvement of calculations with account of seismicity etc.).

The scope of work and the definition of tasks have been written down in the "Specific Technical Terms of Reference" (STOR).

To achieve the intended purpose special work was carried out. The work scope and sequence are shown in Fig. 3.

3.2 Stress analysis

Stress calculations under NOC and SSE for each welded joint were carried out. As the loading factors the total loading from NOC and SSE was assessed. As the input data on the floor response spectra under SSE the results obtained by "Atomenergorpoekt" for site seismicity of 7 for NVNPP and of 5 for Kola NPP were used.

The stratification phenomenon for the surge line in transient regimes was additionally accounted. For its evaluation the results obtained with the temperature measuring system FAMOS installed on the surge line at Kola NPP Unit 1 were used. In Fig. 4 thermocouples installation locations on the outer surface of the pipeline are shown. Figure 5 presents the refined results of temperature measurements obtained with the FAMOS system on the surge line. The analysis of stratification for the surge line at Kola NPP Unit 1 was carried out for the different regimes of unit operation. The stresses were calculated by the conservative approach with no account of pipeline self-compensation effect.

The influence of stratification in the assessment of LBB concept applicability was accounted by introducing an additional safety margin obtained from experience, i.e. the value of the relation of the critical crack length (lp) to crack size at detected leak of 38 l/min (le) was used equal to 2.1 instead of 2.0.

3.3 Analysis of leak monitoring systems and personnel procedures

Reassessment of a current condition of leak detection systems was performed with the purpose of their improvement.

This problem was described in the basic report №2 where the conformance of the existing leak monitoring systems to the requirements for sensitivity and reliability of LBB concept was determined.

There are several types of leak monitoring systems. According to US-NRC requirements for LBB concept application at least three different independent leak detection systems are recommended.

The following three direct leak-monitoring systems exist:

- ALUS acoustic monitoring system (see Fig. 6)
- Activity measurement - radiation monitoring (see Fig. 7)

– Humidity monitoring (At NV NPP only)

In the frame of the assessment of current status of leak detection systems at the reviewed plants the following results were obtained:

- Humidity monitoring system (HMS) was proposed as a missing element for upgrading the leak detection systems at Kola Units 1 and 2;
- The technical Terms of Reference for HMS installation at Kola Units 1 and 2 were formulated;
- The technical Terms of Reference for adaptation of ALUS acoustic leak monitoring system were developed with the purpose to improve system sensitivity in separate sections of the piping.
- The general organization scheme of leak monitoring systems interaction was reviewed. It consists of systems of direct leak monitoring and also of leaks detection by indirect symptoms.

It was shown that alongside with the available systems of signals interpretation directly from the (leak) sensors (dedicated leak monitoring systems) there are a number of systems capable to detect a coolant leak by means of indirect symptoms. Figure 8 presents the general organization scheme of coolant leak monitoring systems interaction for VVER-400/B-230 NPP.

Upgrading/amending of operation procedures for NPP personnel actions at leak detection was performed.

The assessment describes the procedures for personnel, how to react in case of identifying a leak in the primary circuit. The leak monitoring systems, their performance and threshold values were determined.

For Kola-NPP as well as for Novovoronezh NPP there exist the procedures for personnel, which describe actions that are to be taken in case of leak detection by any direct or indirect indications.

Information on the scope and frequency of training and examination of the knowledge of these procedures by NPP personnel was additionally presented.

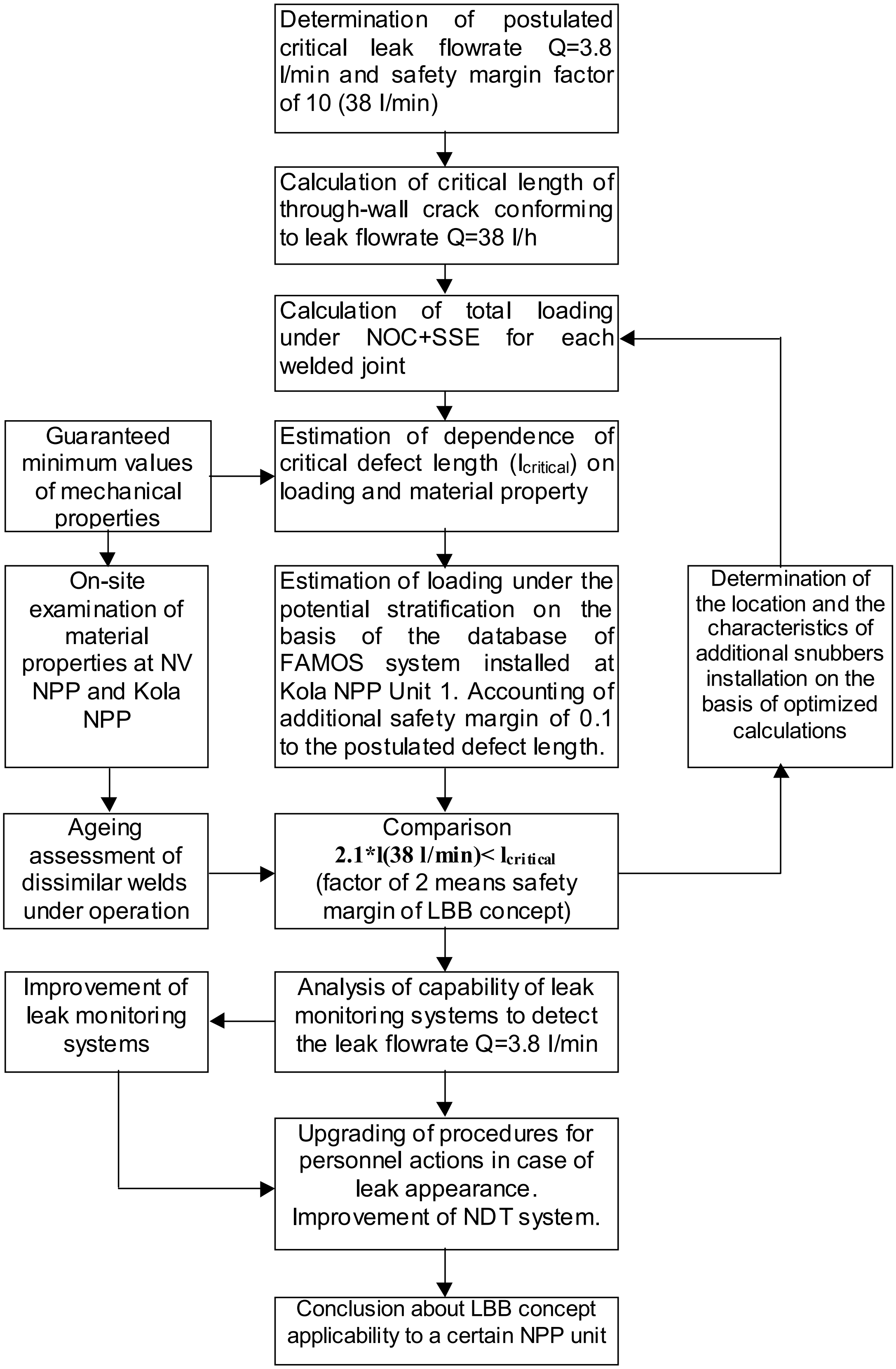

Figure 3. General diagram of calculations for LBB concept applicability analysis.

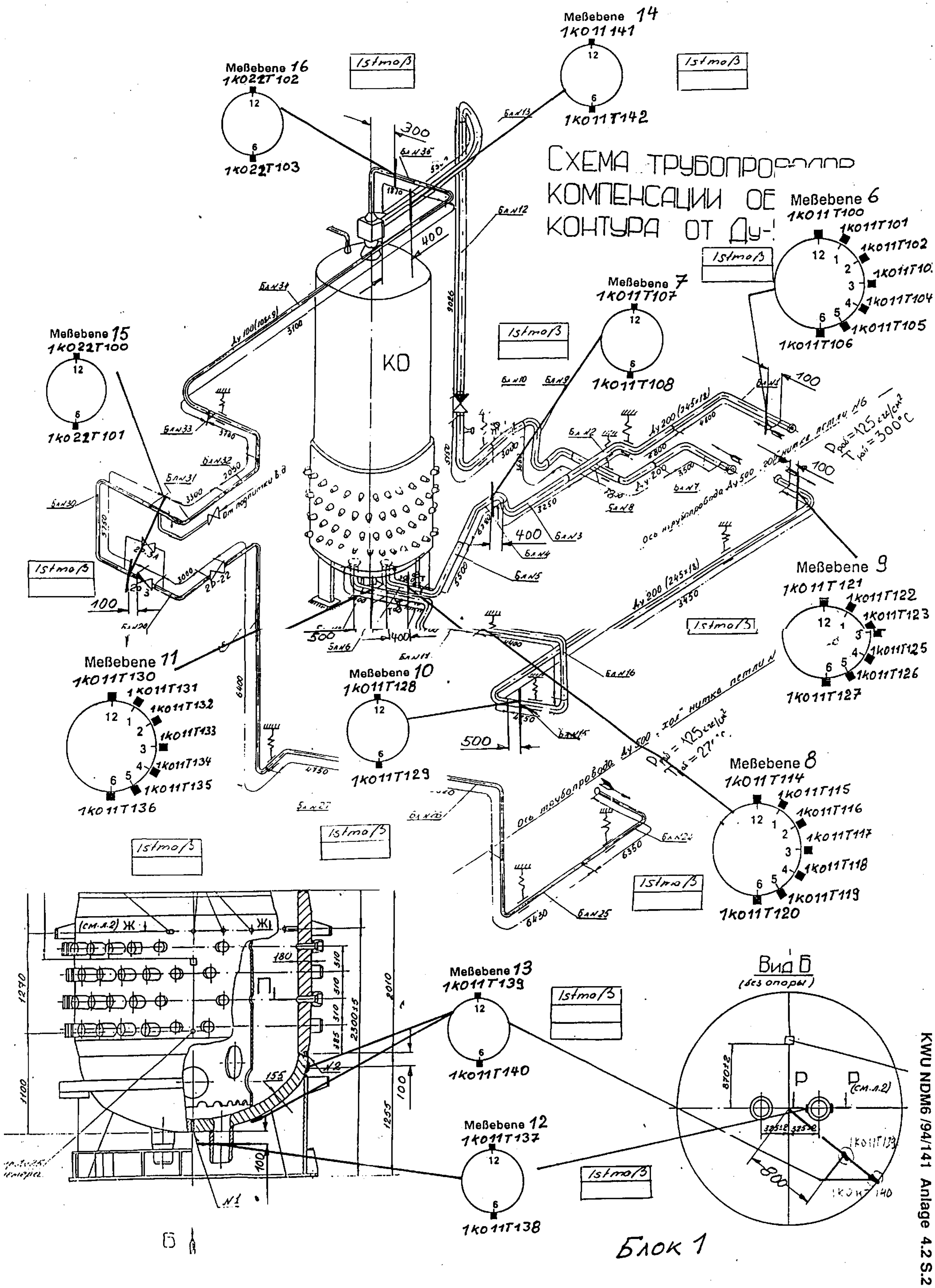

Figure 4. General Outlay of FAMOS temperature measuring system installed at Kola NPP Unit 1

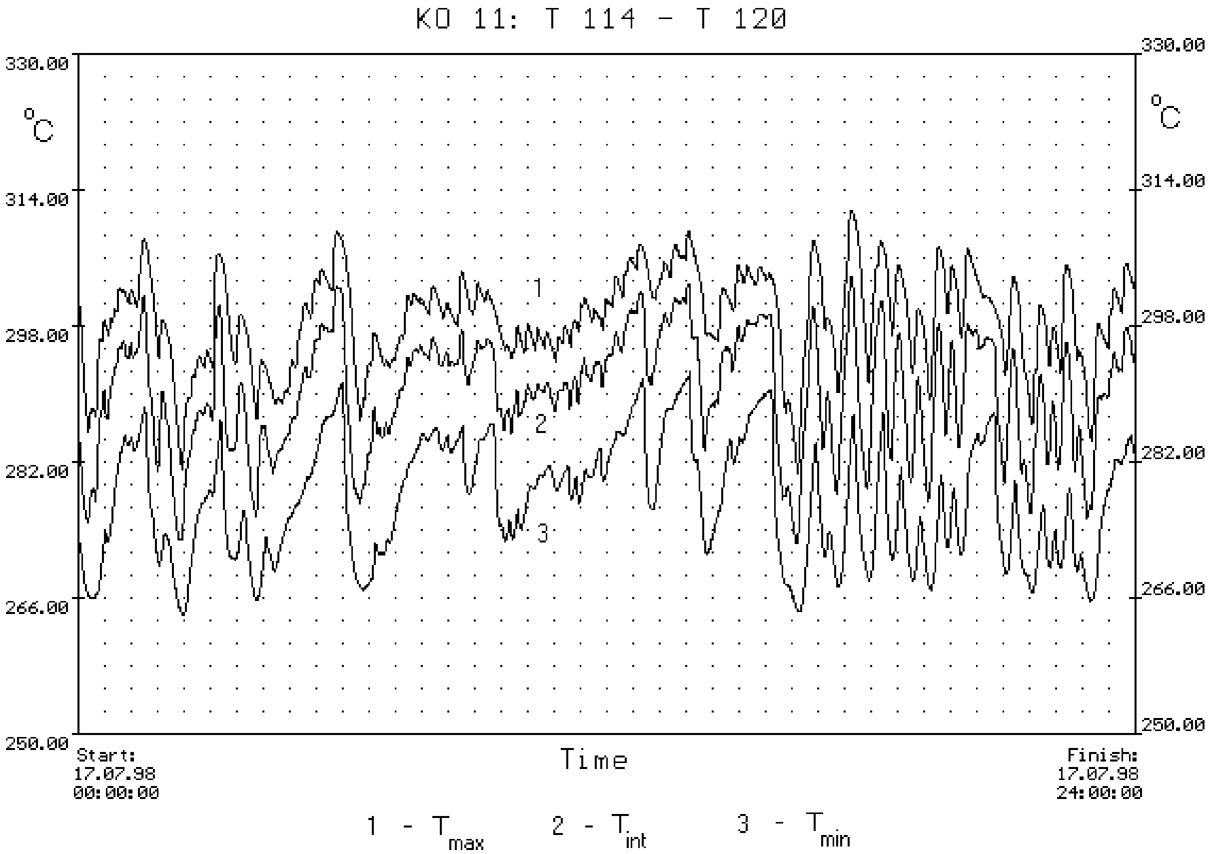

Figure 5. Result of stratification phenomena meashurement in cross-section 8 of the surge line (thermocouples 1KO11T114-T120) at Kola NPP Unit 1.

Notes:

Tmax - maximal measured temperature;

Tmin - minimal measured temperature;

Tint - the current mean-integral value of temperature along the pipe cross-section perimeter.

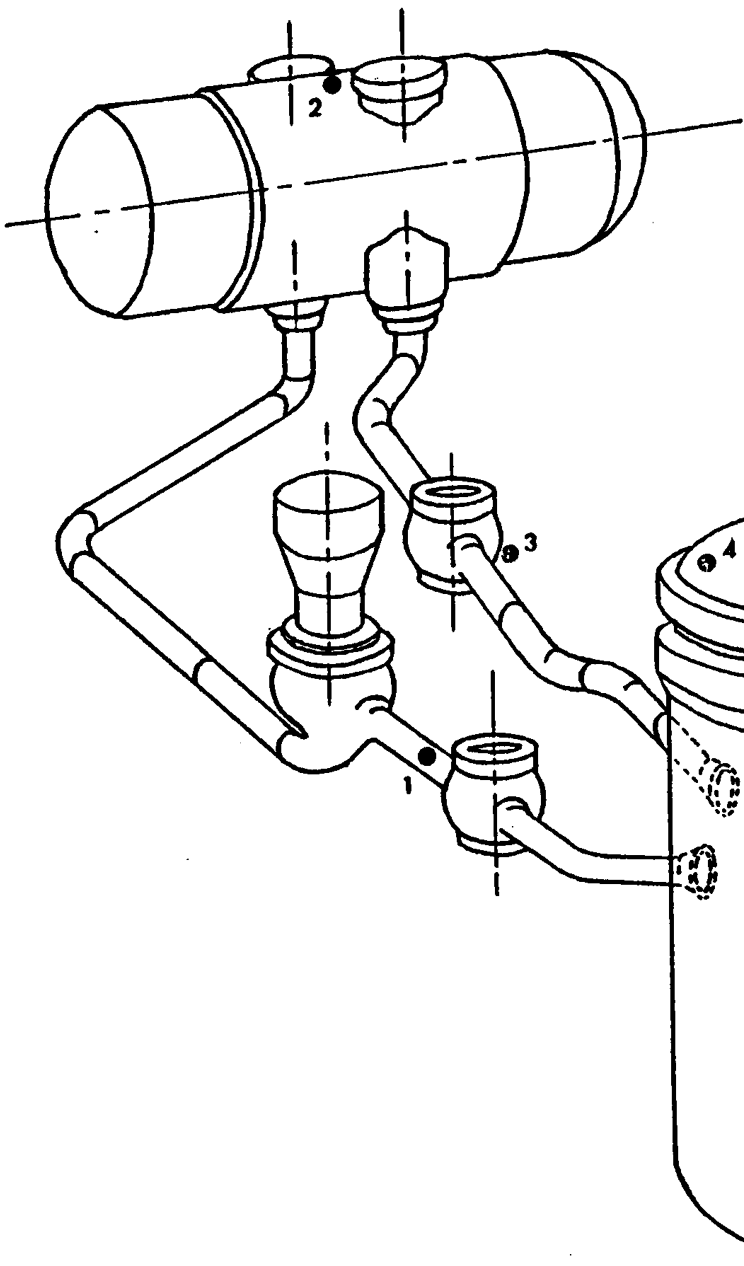

Figure 6. General sensors layout of ALUS acoustic leak monitoring system
1 – sensor on MCL section between MCP and main safety valve at "cold" leg;
2 – sensor on SG vessel;
3 - sensor on main safety valve at "hot" leg;
4 - sensor on reactor pressure vessel.

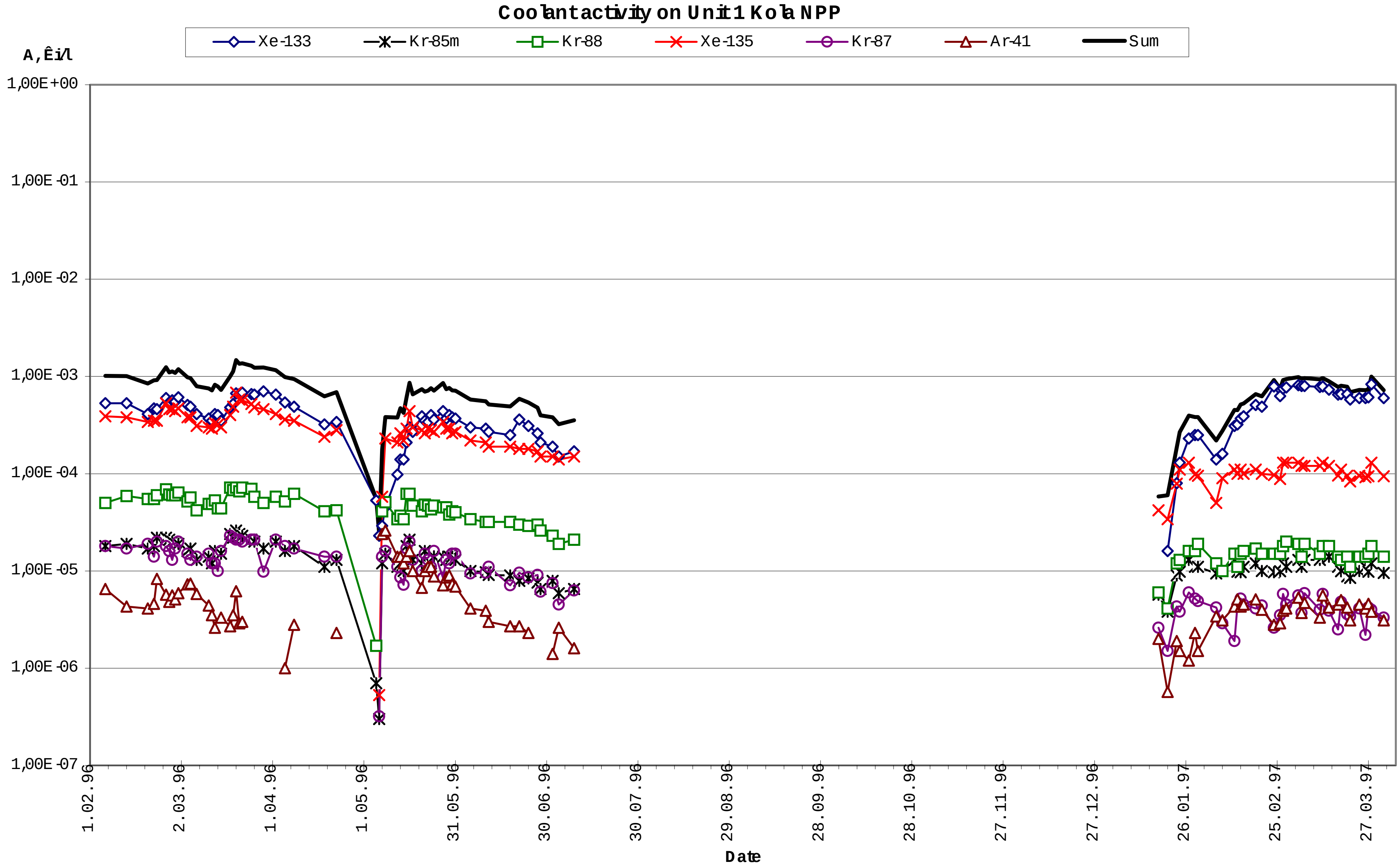

Figure 7. Example of a diagram demonstrating coolant activity changing at Kola NPP Unit 1

3.4 Dissimilar welds ageing assessment

Taking account of the actual operation time of first generation plants the assessment of MCL dissimilar welds ageing was carried out.

First of all, the dissimilar welds (austenitic to perlitic steel) between the safe-ends of RPV nozzles and MCL and pressurizer nozzle to surge line were assessed.

In the frame of TACIS 91-1.2 project Framatome performed ageing tests of dissimilar welds to prove their required toughness. In addition to these data, at Nuclear Research Institute (NRI, Rez, Czech Republic) jointly with Russian experts separate tests were performed. During these tests the material was artificially aged from 3000 to 10000 h at temperatures of 325 °C and 425 °C.

The investigation showed the following:

No change of strength properties and $J_{0.2}$ value due to the heat treatment ageing is observed.

The test results (high toughness values) of the heat-affected zone indicate acceptable toughness of the welded joints after long ageing.

Degradation of Ccharpy impact toughness due to thermal aging is found only in the 2nd buttering layer but there is obviously a saturation effect.

For the second and third buttering layer of the weld in mock-up a small increase of ferrite content was found.

On the basis of the analysis of obtained results the following recommendations were made:

- Based on the indicated change in the impact toughness properties of only the 2nd buttering layer in the mock-up sample weld further investigations of the nature of the degradation mechanism at extended ageing heat treatment is recommended.
- Ferrite content in the second and third buttering layer of the mock-up weld was also investigated on a test-specimen of NPP Greifswald. Metallographic investigations on the RPV nozzle of NPP Kozloduy Unit 1 also confirm low ferrite content in the second and third layer (0 - 3 %). Therefore, metallographic investigations on the RPV nozzle are recommended for at least one nozzle of each Unit of Novovoronezh and Kola NPPs.

3.5 Improvement and optimization of ISI system

The directions of further upgrading and the development of Terms of Reference for improving of in-service inspection (ISI) system at VVER-440 of the first generation were identified.

According to existing “Procedures for in-service inspection of base metal and welded joints of components and piping of primary and secondary circuit of VVER-440 plants " AIE-2-95, the requirements to ISI were identified and the analysis of actual metal condition on the basis of these requirements implementation was performed. The scope, technologies, frequency of non-destructive examination including the description of the hardware and its performance characteristics are described.

The analysis of the existing ISI system was performed taking into account the computed piping sections with maximum loading from the viewpoint of LBB concept application. The results of calculation are presented in «LBB-Handbooks» (see Fig. 9).

The analysis of inspection practice of welded joints of VVER-440/230 primary circuit piping at the stages of fabrication, mounting, pre-service and in-service inspection has allowed to make the conclusion about the eligibility of welded joints for LBB concept application. Many years of experience with ISI at considered NPPs including the ultrasonic testing by automated systems of SIEMENS confirm the absence of defects in the welded joints of primary circuit piping.

In the frame of Terms of Reference elaboration for in-service inspection system improvement with account of NPP operation experience the efforts in the following areas were recommended:

- Novovoronezh NPP Units 3 and 4:

- Additional sections of surge lines shown as critical in the “LBB-Handbook. NV NPP Units 3, 4” should be included in the scope of ISI programme by PT and UT for the next scheduled preventive maintenance outage.
- The frequency of inspection by PT and UT for these sections should be increased from 1 every 6 years to 1 every 2 years for the next 4 years of operation.
- It is recommended to equip NVV NPP also with an automated system of ultrasonic testing of MCL circumferential and longitudinal welds similar to SIEMENS equipment installed at Units 1,2 of Kola NPP.

- Kola NPP Units 1 and 2:

- Additional sections of surge lines shown as critical in the “LBB-Handbook. Kola NPP Units 1, 2” should be included in the scope of ISI programme by PT and UT in the next scheduled preventive maintenance outage.
- The frequency of inspection by PT and UT for these sections should be increased from 1 every 6 years to 1 every 2 years for the next 4 years of operation.

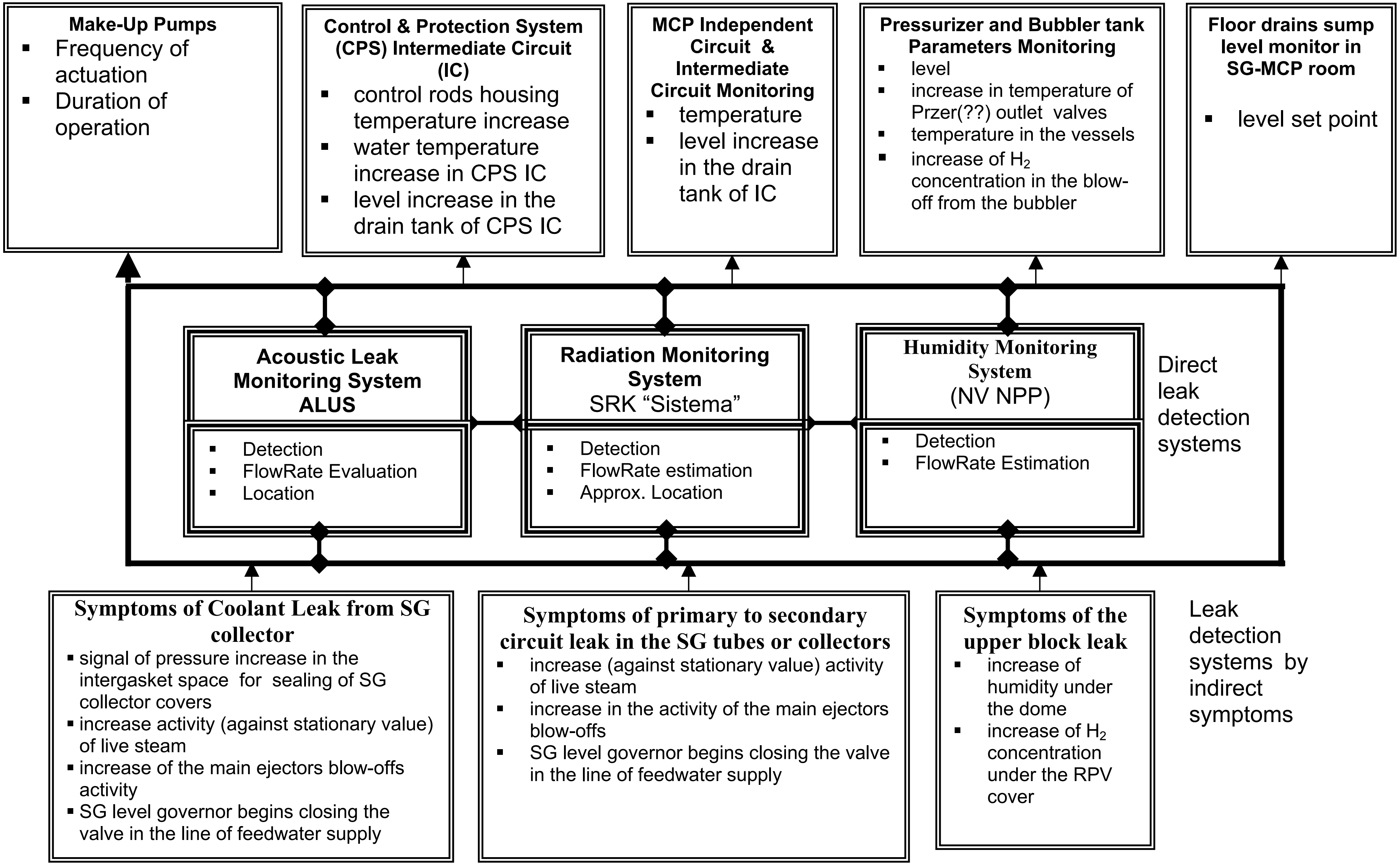

Figure 8. General Schematic of Leak Detection System

3.6 LBB Handbooks for Kola NPP Units 1 and 2 and NV NPP Units 3 and 4

Within the frame of the project "LBB Handbooks" were developed, which summarize LBB analysis for the main circulating lines and surge lines of Kola NPP Units 1 and 2 and NV NPP Units 3 and 4.

To conduct LBB applicability analysis the following main assumptions were used in these Handbooks:

- degradation due to erosion and corrosion is negligible;
- potential probability for water hammer is negligible;
- potential for properties degradation due to thermal, vibration and mechanically induced fatigue is extremely low;
- site seismicity of 7 for NVNPP and of 5 for Kola NPP by MSK-64 scale were used.

Together with the validation of negligible fatigue crack growth during the design lifetime these assumptions were assessed for the similar unit of Bohunice V1 plant (defects estimation was carried out according to ASME XI)

During the development of these documents the following results were obtained:

The LBB requirements according to the employed US procedure of LBB concept applicability are met for the whole MCL and SL of Kola 1, 2 and Novovoronesh 3, 4 provided the additional snubbers are installed to reduce seismic stresses, and the installed leak detection systems are capable to detect the required leak rates of 3.8 l/min.

Some of existing leak detection systems fulfil this requirement (for instance system of air activity measurement in plant rooms, humidity monitoring system). Other systems should be upgraded (e. g. acoustic leak monitoring system (ALUS) for certain sections of MCL).

The optimized number, type and location of additional seismic snubbers were proposed for each inspected unit separately (on the basis of numerous stress analyses of the primary circuit taking account of floor response spectra). An example of calculated results of LBB concept applicability for NV NPP Unit 3 with indications of the critical sections and locations of additional snubbers installation is shown in Fig. 9.

Re-evaluation of calculation results in conformity with German approaches - FSC/PLL and PLL was performed.

The following conclusions were made:

- LBB requirements are fulfilled for both approaches (FSC / PLL and PLL), i. e. half of the critical crack length exceeds the crack length of specified leak.

- The corresponding safety margins are higher for MCL compared to surge lines both at Kola I, 2 and at NV NPP 3, 4 (independent of the approaches used).

- For MCL the US approach gives higher safety margins than the German approach, and for the surge lines the situation is quite the opposite.

The calculations of the number, type and location of additional seismic snubbers were proposed and the cost of installation was estimated.

As a result of work the Terms of Reference were prepared which specify the required technical characteristics of the additional snubbers. An example of characteristics of the additional snubbers to be installed at NV NPP Unit 3 is presented in Tables 1, 2 below.

The approximate cost analysis for purchasing, delivery and mounting of these snubbers was performed. It was carried out on the basis of similar installation works of GERB type snubbers (Westinghouse) and LISEGA type snubbers (installed at NPP «Mochovce»). The estimated total cost of this work is approximately 730 000 Euro.

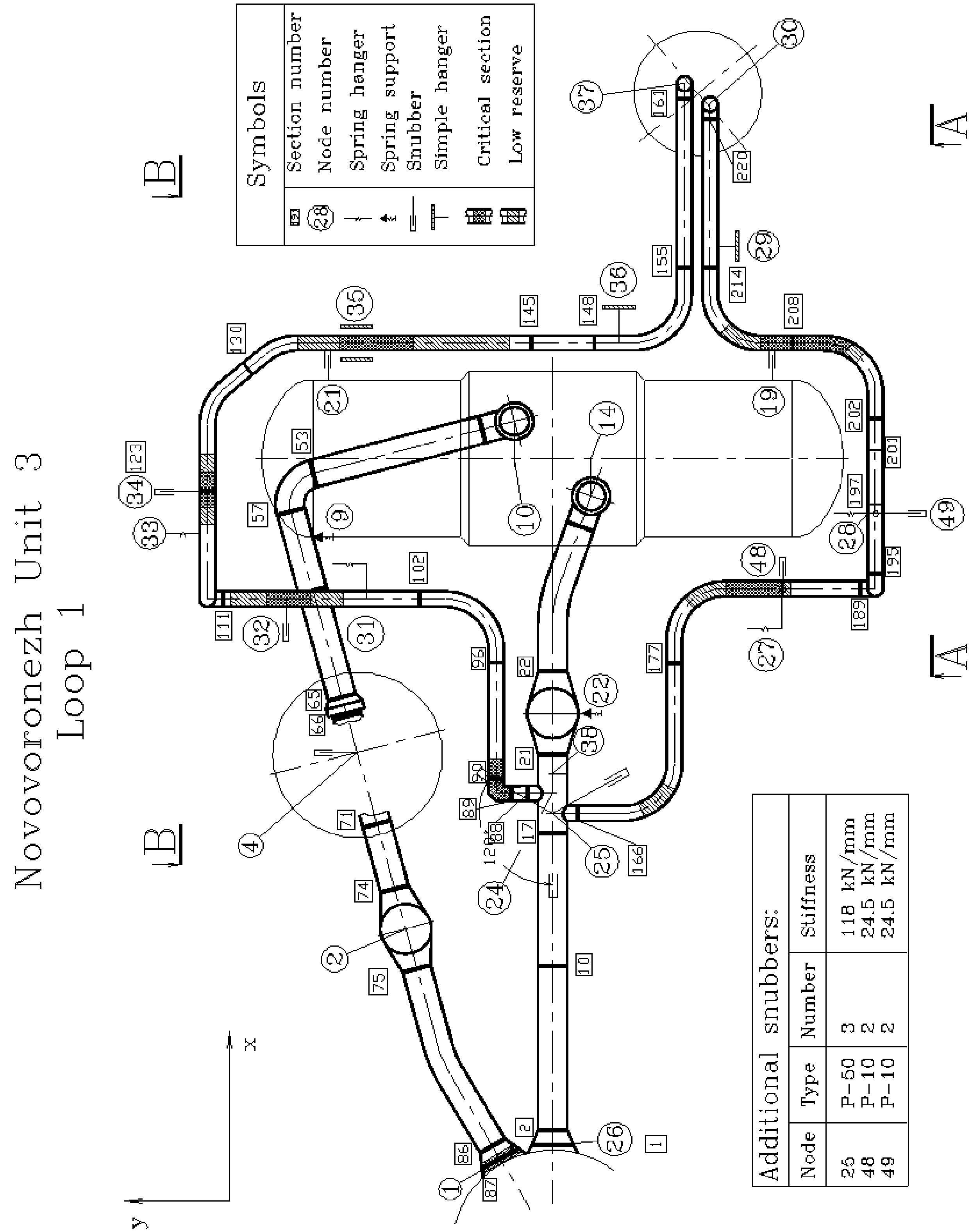

Figure 9. Example of LBB concept analyses results: The number, type, location of seismic snubbers for NN NPP Unit 3

Table 1. List of additional snubbers to be installed at NV NPP Unit 3

Type	Number	Computer model node (snubber location point)
P-50	3	25 (surge line right branch connection to MCL)
P-10	2	48 (surge line right branch, in front of rising pipe)
P-10	2	49(surge line right branch, upper part behind rising pipe)
P-50	3	4 (MCP)
P –170	2	21 (SG)
P –170	2	19 (SG)
P-10	2	34 (surge line left branch, upper part behind rising pipe)
P-10	2	32 (surge line left branch, in front of rising pipe)

Table 2. Snubbers specification

Type	Stiffness [kN/m]
P-50	1.18×10^5
P-10	2.45×10^4
P-170	$2,93 \times 10^5$

3.7 Overview of the TACIS R2.16/93 project results

The LBB requirements according to the used US-procedure are met for the whole MCL and SL of Kola 1, 2 and Novov. 3, 4 provided that additional snubbers (hydraulic shock absorbers) are installed to decrease seismic stresses and the installed leak defection systems are capable of detecting the required leak rates of 1 gpm = 3.8 l/min.

Some of the actual leak detection systems (LDS) are able to fulfill this requirement (e.g. activity measurement of containment air, moisture monitoring, if available) and others have to be upgraded (e.g. acoustic leakage monitoring system (ALMS) for the MCL).

The optimized number, type arid location of these snubbers are proposed for each plant separately (on the basis of numerous stress analyses of the primary circuit).

4 DISCUSSION AND PRACTICAL ASPECTS OF THE WORK CONTINUATION

Under the TACIS R1.2/91 and it continuation TACIS R2.16/93 projects the calculations and experimental analysis of LBB concept applicability to Novovoronezh NPP Units 3 and 4 and Kola NPP Units 1 and 2 were performed. It was shown that LBB concept could be applied to the above units both under normal operation conditions and under additional seismic loading (NOC+SSE regime). Conditions for LBB concept applicability with simultaneous achieving of required probability level of MCL operation reliability were demonstrated.

At present the situation with LBB concept application to the VVER-440 (V-230/179) was changed as follows:

- More realistic data on seismicity level at Novovoronezh NPP site was obtained under the investigations performed by Earth Physic Institute of Science Academy of Russia. It was shown that calculations of stresses under the safe shutdown earthquake (SSE) should be carried out for the site seismicity less than 5 of MSK-64 scale.
- The new regulatory paper “Guideline on the “Leak before Break” concept applicability to the NPP piping R-TPR-01-99” RD 95 10547-99 was authorized in 1999. This paper states some additionally requirements in comparison with the previously existed "Technical Requirements to the Application of the 'Leak Before Break' Concept for Piping of NPPs in Operation" (M., VNIIAES,1995).
- Within the frame of work on the “Profound safety ensuring” additional regimes was added to design. Thus these regimes (transients) should be also analyzed.

Taking in account these data and new regulatory requirements the results of LBB analysis obtained within TACIS projects should be partially reviewed and updated. For the practical application of the LBB concept with the re-assessed seismicity data the following path was chosen (see paths 2 and 3 in item 3.1 beforehand): to determine an acceptable level of stresses in MCL and surgelines in all new operation regimes along with improvement of non-destructive examination This work is performed by VNIIAES in collaboration with Russian Institutes. Here it should be noted that during the scheduled preventive maintenance outage of 1999-2001 the specialists of VNIIAES, Gidropress and NPPs performed on-site examination of mechanical properties, structure and integrity of metal at NV NPP Units 3, 4 and Kola NPP Unit 1 after 200 000 hours of operation. The program of inspection placed special emphasis on the critical sections of MCL and surge lines determined in the frame of LBB concept applicability analysis under the TACIS R2.16/93 project. Sections such as welded joints of the surge lines with MCL, dissimilar welds of "hot" and "cold" reactor nozzles to MCL were specially examined. Also, within this work the inspection procedure was developed and the automated ultrasonic inspection system “Avgur 4.2” was applied, that considerably increases the inspection accuracy and provides the geometry of detected flaws.

Simultaneously, the calculations of probability of double-ended guillotine break and probability of leak initiation in base metal and in weld metal both for MCL and surgelines were carried out. The results of this work will be used for Safety Probability Analysis.