
International Review of Kursk Unit 1 In-Depth Safety Analysis Report

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Abstract: The paper presents the objectives, organisation, main findings and conclusions of the international review of the Kursk Unit 1 Safety Analysis Report (K1IRSR). The K1IRSR was administered by RISKAUDIT IRSN/GRS International and carried out by international experts from 7 Western countries plus the Russian Federation, under the supervision of the Safety Review Group (SRG) of the European Bank for Reconstruction and Development (EBRD). The project was financed by the Nuclear Safety Account (NSA) administered by the EBRD. The Russian Experts worked under a contract with IBRAE financed by Rosenergoatom. The main conclusions were that the SAR followed a correct approach, broadly in line with Russian and international guidance documents, but needed improvement in structure and content. It established that the safety level of the unit has been increased significantly by the modernisation programme. The important deviations of the unit from current Russian regulations and the IAEA safety issues for RBMK are either fully resolved or are being addressed to the extent possible by compensatory measures to further reduce the risk. The K1IRSR experts have made a number of recommendations for improvement of the K1SAR. The authors agreed to take the recommendations into account in future revision of the K1SAR.

1 INTRODUCTION

The Kursk nuclear power plant (KuNPP) comprises four 1000 MWe RBMK units. Units 1 and 2 are first generation units. They were commissioned in 1976 and 1979. Units 3 and 4 are second generation and were commissioned in 1983 and 1985. The main differences between the two generations are in the originally designed emergency cooling systems and in the reactor confinement systems.

The RBMK is a graphite moderated, pressure tube, boiling water reactor. The fuel elements are mounted into 1693 pressure tubes. Additionally, there are channels for the control and protection system (CPS) which are cooled by an independent CPS cooling circuit.

The reactor is enclosed in a tight metal structure: the reactor cavity. The reactor circuit is divided into two parts, which are located in compartments. However, the compartments of the first generation of RBMK are not designed to serve as an accident localisation system.

The Chernobyl accident and the subsequent safety analysis revealed significant gaps in the inherent safety characteristics of the RBMK reactors and their operation. After the generic

post-accident modifications that were applied to all RBMK units, Kursk NPP undertook an extensive step by step modernisation programme over the last ten years.

In June 1995 the Government of the Russian Federation and the European Bank for Reconstruction and Development (EBRD) concluded an agreement on activities of the Nuclear Safety Account (NSA) in the Russian Federation, including an International Review of an In-Depth Safety Analysis Report for Kursk NPP Unit 1 (K1SAR). The K1SAR was completed in October 2000 by the utility Rosenergoatom (REA) and Kursk NPP (KuNPP) on the basis of the Guidelines for In-depth Safety Analysis (RF Guidelines) issued in 1997 by the Russian Regulatory Body Gosatomnadzor (GAN RF), now named Federal Nuclear Regulatory Authority of Russia (FNRAR). It was reviewed in 2001 by the Scientific and Engineering Centre for Nuclear and Radiation Safety (SEC NRS) for GAN RF.

A team of international experts, designated by the EBRD and the Government of the Russian Federation, performed the International Review (K1IRSR) of the K1SAR.

This paper presents the objectives, organisation, and the main findings and conclusions of the K1IRSR review work.

2 OBJECTIVES

The main objectives of the K1IRSR were:

- a) To conduct K1IRSR in accordance with internationally recognized safety principles, internationally formulated safety guidelines and established practices as expressed e.g. in documents of the International Atomic Energy Agency (IAEA),
- b) To review compliance of K1SAR with the “Guidelines for the in-depth safety assessment of operational NPP units with VVER and RBMK type reactors” (RF Guidelines).
- c) To submit the K1IRSR results to Gosatomnadzor for their consideration.

3 ORGANISATION OF THE REVIEW WORK

The K1IRSR was administered by RISKAUDIT IRSN/GRS International and carried out by international experts from 7 Western countries plus the Russian Federation, under the supervision of the Safety Review Group (SRG) of the EBRD. The team consisted of experts from: AECL (Canada), Batelle PNNL (USA), ES Konsult (Sweden), GRS mbH (Germany), IRSN (France), NNC Limited (UK), NRG (The Netherlands), SERCO Assurance (UK), SCIENTECH Inc. (USA), together with Russian experts under the lead of IBRAE. The project was financed by the NSA. The Russian Experts worked under a contract with IBRAE, financed by REA.

The K1SAR documentation included:

- General Information on Unit 1 of KuNPP (KuNPP-1)
- Safety Concept
- Site Characteristics
- Systems Analysis

- Deterministic Analysis of Operational Transients and Design Basis Accidents (DBA)
- Probabilistic Safety Analysis
- Analysis of Beyond Design Basis Accidents (BDBA) of ATWS Type
- Operational Safety of the Unit
- Analysis of Operating Experience of KuNPP-1
- Environmental Impact Assessment
- Unit modernisation Programme
- Summary Assessment of the Current and Predicted Safety Level of the Unit
- Planning of Further Safety Improvements
- Summary Safety Assessment of the Unit

The K1IRSR was organised into Task groups in accordance with the above structure.

The international review was performed in two phases. In March 2002, Phase 1 of the K1IRSR concentrated on checking the comprehensiveness and completeness of the K1SAR, and on a preliminary assessment of selected key safety issues, known from the experience of the experts in previous safety assessments of NPPs with RBMK reactors.

Based on the results and the lessons learned during Phase 1, the SRG recommended that Phase 2 maintain a broad overview but with a focus on the key safety issues:

- Adequacy of the new Integrated Instrumentation, Control and Protection System (IICPS)
- Adequacy of the new Emergency Core Cooling System (ECCS)
- Completeness of internal and external hazards covered in the K1SAR
- Completeness of initiating events and accidents covered in the K1SAR
- Boundary between DBA and BDBA
- Structural integrity
- Applicability of computer codes.

Phase 2 consisted of a detailed review of selected documents of the K1SAR, with extensive exchange between the K1IRSR and the K1SAR experts. The Experts performed visits to the KuNPP-1 site as needed to complement their information. These visits were also essential for an efficient exchange during the review between the K1IRSR experts and the operator.

4 MAIN FINDINGS OF THE REVIEW

4.1 K1SAR Documentation

The complete Summary Volume and large amounts of the supporting documentation of the K1SAR were studied by the K1IRSR team. The review concluded that the K1SAR was

generally in accordance with the RF Guidelines and internationally accepted requirements. Simultaneously it was concluded that the K1SAR needs to be further enhanced in structure and content, and recommendations were made in this respect. For example:

- Many sections of the K1SAR were found to contain insufficient detailed information
- Required analyses of BDBA are missing, apart from ATWS
- There was no systematic assessment of the degree of the defence-in-depth
- There was no quantitative reliability analysis of systems
- Equipment qualification is not discussed in relation to systems
- There was no comprehensive analysis of the impact of internal and external hazards on the systems and their operation
- There was no discussion of safety culture.

4.2 Safety Concept

KuNPP-1 is a first generation plant the design of which did not foresee a confinement system. This is a deviation from the now widely accepted defence-in-depth concept as described for example in IAEA guidelines. Such plants require an in-depth justification for the absence of a confinement system. This issue is taken into consideration in the K1SAR safety analysis. However, the reviewers recognised that backfitting of an accident localisation system is practically impossible but they note that, in addition to safety justification including the design basis accident analysis presented in the K1SAR, compensatory measures and supporting analyses are being developed, and are planned to be implemented. The reviewers believe these measures and analyses are necessary, and support their implementation, which includes:

- Demonstration of the inherent safety characteristics of the reactor
- Leak Before Break demonstration for large diameter piping, including introduction of technical measures
- Full scope Probabilistic Safety Analysis.

The justification for the absence of a confinement based on these measures will be further developed in future revisions of the K1SAR.

The reviewers understand that the authors will make more explicit response to each of the deviations from the requirements of the RF Guidelines in the next iteration of the K1SAR. Extensive repetition should be avoided but it would be of value to future review to include better summarised statements and cross references in all places required by the Guidelines.

4.3 System Analysis

4.3.1 Integrated Instrumentation, Control and Protection System (IICPS)

KuNPP-1 recently installed this system, completely replacing the CPS of the original design. Its design addresses the main shortcomings generic to RBMK CPSs, in particular their lack of diversity and segregation. It includes two independent shutdown systems, AZ and BSM.

The role of the IICPS is to undertake (a) the reactor power control and monitoring functions, and (b) the automated reactor protective functions, required for safe operation of the plant under normal, incident and accident conditions.

The above role is undertaken by an integrated system that is arranged broadly as follows:

- Two sets of sensing and logic equipment, each set being subdivided into an ICPS part that monitors reactor physics parameters, and an AZRT part that monitors process parameters
- A common part incorporating the reactor power controllers and control room interfaces for remote control and operator information
- An AZ shutdown system incorporating 33 fast-acting rods located in gas-filled channels with water film cooling of the AZ rods and a BSM shutdown system incorporating 158 rods located in water-filled channels.

The AZ system fulfils only a protection function and provides for a fast shut down of the reactor. The rods of the BSM system provide control and protection functions. Only the BSM system is designed to achieve and maintain long term cold shutdown conditions. This is in accordance with the Russian regulations. The two sets of sensing and logic equipment are diverse from each other, and the AZ equipment is diverse from the BSM equipment. This diverse equipment is located in separate equipment rooms.

The most important findings were:

- The absence of a fault schedule, covering all the Postulated Initiating Events (PIEs) included in the plant design basis, to underpin the IICPS design. A fault schedule would summarise the ability of the IICPS to deal with each PIE in turn, and show in a systematic way that there is full and adequate protection.
- The lack of a demonstration that the system software, which is a key element of the system, is sufficiently reliable.
- Diversity and Reliability of SCRAM are greatly reduced when one of the sets is taken out of service during reactor operation for maintenance or repair. The total amount of time per year during which this situation can exist is not limited by regulations. There is no analysis that demonstrates that the effect of this on the SCRAM reliability is acceptable.

4.3.2 *Emergency Core Cooling System (ECCS)*

The ECCS at KuNPP-1 has been upgraded twice. In the original design, short-term make-up was provided by realignment of the main feed water pumps (PEN) and long-term make-up by three emergency pumps (APEN). In the first phase of modernisation (1994-1997), small accumulators with quick-opening valves were installed to improve short-term make-up, and two more APEN pumps were added to support long-term make-up. In the second phase, all the existing equipment was grouped into one train ("ECCS-1") and a second train was installed ("ECCS-2") with its own set of large accumulators and five more emergency pumps.

The ECCS-2 is designed in line with Russian and international requirements for safety systems.

The ECCS as a whole (i.e. ECCS-1 plus ECCS-2) is close to modern standards (diversity and segregation between trains, common cause failure, automatic action), but may fall short in terms of redundancy; inconsistent statements of the success criteria for long-term make-up cause the level of redundancy to be unclear, while the Single Failure Analysis incorrectly ignores permitted maintenance outages of pumps, and so exaggerates the redundancy. In

addition, there is insufficient segregation within each train to defend against area events, which represents a non-compliance with good modern practice.

The reviewers made the following observations about the system and its operation:

- The boundary conditions (e.g. primary circuit pressure) during functional testing of the ECCS-2 accumulator train do not correspond to those in DBA.
- The permitted maintenance outages for ECCS-2 components seem excessive (allowing unlimited maintenance for one pump and limited maintenance for a second).
- There is very little physical segregation of the ECCS-2 pumps, and also of the accumulators in room 200/1 B-005.
- Oil leaks from the PEN pumps could be a source of fire risk in the turbine hall since there are no bunds to prevent the spread of any leak.

The reviewers endorse the proposals outlined in the K1SAR for improving the instrumentation and power supply to parts of ECCS-1.

4.3.3 Other Systems

The modernized **Emergency Power Supply System (EPSS)** consists of two separated, segregated trains: EPSS-1 and EPSS-2, each supported by diesel generators (DGs). The DGs for the first train share a building (in particular the DG control room) with the DGs for unit 2; those of the second train are in a separate building. The first and second trains supply power to the first and second trains of the ECCS (i.e. ECCS-1 and ECCS-2), respectively, and to other consumers. The trains have sufficient capability and capacity for supplying safety and safety-relevant loads with internal redundancy. The second (new) train is independent in its support functions from EPSS-1 (e.g. cooling for EPSS-2 is provided from a dedicated spray pond as compared to EPSS-1, which uses the original service water system).

The reviewers' observations on the EPSS included the following:

- The set point at 25% of nominal voltage for actuation of the reactor shutdown and the start of the emergency DGs, specified in the Russian regulations, is too low and could lead to serious consequences for safety / safety related components (drives, pumps).
- The transfer pumps (NDK) supplying water to ECCS-2 appear to be powered only from EPSS-1. It means that, in the long term, operation of ECCS-2 needs both trains of EPSS.

The **Reactor Cavity Protection System** vents the reactor cavity (RC) in the event of rupture of a limited number of pressure tubes, thereby preventing over-pressurisation that could lead to uncontrolled release of activity to the environment.

The rupture of one pressure tube is the design basis for the system. However, there is no justification that a larger number of ruptures does not need to be treated as DBA. This generic RBMK question is still open and the experimental and theoretical studies currently under way in this area will be particularly important in addressing this issue.

The cavity discharge capacity has now been increased so that it can cope with up to 9±4 ruptured pressure tubes. However, if the safety devices (rupture discs) are actuated, radioactivity will reach the environment largely bypassing the condensing and scrubbing path since there is no Accident Localisation System at KuNPP-1.

A temperature sensing system has been installed in the RC discharge lines. This provides diversity to the RC high pressure signal initiating reactor scram on pressure tube rupture.

The **Primary Coolant Overpressure Protection System** consists of eight main safety relief valves, each actuated by a pilot valve backed up by an electromagnetic drive, discharging to two bubble condensers. Its capacity was reduced by 50% from that of the original design, in order to reduce the maximum impact of stuck-open valves. The current capacity of the system is sufficient for the worst DBA scenario.

The reviewers note that the cargo-lever drives of the pilot valves do not comply with current Russian standards, and support the K1SAR recommendation that they be replaced.

The main **Service Water System (SWS)** at KuNPP-1 rejects heat to an artificial lake fed by the river. The capacity of the SWS is far in excess of what is needed for safety, so the only important failures are those that would lead to its complete failure.

A separate new additional service water system for safety systems (SWS-SS), rejecting heat to spray ponds, provides cooling for the diesel sets of EPSS-2 (independent of EPSS-1). The SWS-SS appears to be robust and able to fulfil its task under a wide range of hazard conditions.

In contrast to ECCS-1, the ECCS-2 pump motors and bearings are self-cooled, and need no service water. This is an important benefit of the modernisation programme, greatly reducing the importance for safety of the SWS.

The **Reactor System** consists of the fuel assemblies and elements, the fuel channels, the control rod channels, the graphite stack, the biological shielding and the metals structures that support everything else. The main safety issues revolve around the ability to (a) monitor the integrity of the structures and (b) detect leaks in the fuel elements.

Other points to note are that:

- All pressure tubes have been replaced and graphite gap restored during 1994 -1997.
- The conversion to erbium fuel is favourable from the safety point of view.

The **CPS cooling system** circulates water through the control rod, instrumentation and reflector channels to cool them. The main safety issue is that a large leak from the system would increase void in the core, increasing reactivity and requiring rapid shutdown of the reactor. The reactivity effect will be reduced by gradual introduction of a new rod design, although currently the system can fulfil its functions. The protection against de-watering of the system is adequate, satisfying the single failure criterion, and with good redundant and diverse monitoring of fault conditions.

4.4 Accident Analysis

The **analysis methodology** divides **Design Basis Accidents** (DBA) into Loss-of-Coolant-Accidents (LOCAs), Reactivity Initiated Accidents (RIA), Operational Transients caused by equipment failures and Refuelling Accidents. RELAP5 is used to analyse LOCAs, Operational Transients and Refuelling Accidents, and SADCO is used for reactivity transients and to provide the neutron-physical boundary conditions for the RELAP5 analyses.

The K1SAR contains inadequate information about the validation of the SADCO code suite for analysis of RBMK reactivity transients. The validation work needs to be completed. To a lesser extent a similar comment applies to the validation of RELAP5. The certification of RELAP5 by GAN RF for RBMK licensing calculations is expected to happen soon.

The K1SAR documentation on Accident Analysis does not present the complete safety justification for the safe operation of KuNPP-1. The set of accidents analysed does not include all those specified in the Guidelines for ISA as being within the Design Basis. The documentation shows convincingly that the operational transients omitted are bounded by those analysed. The omission of Loss of Service Water to the ECCS is reasonable given that the new ECCS-2 pumps are self-cooling. However, the argument that loss of Service Water is not possible needs justification.

Furthermore, several important LOCAs in the GAN RF list are not analysed deterministically. They are: Rupture of Main Feed Water Line, rupture of Main Steam Line, rupture of Main Circulation Pump (MCP) Pressure and Suction Header. This is in contrast to analyses for other RBMKs where these events are DBA. Although these accident sequences are considered to be BDBA for first generation RBMKs, there is no deterministic justification for this in the K1SAR. Some of these analyses might have been performed for other RBMK, and some KuNPP-1 specific analyses are in progress. If these accidents are in fact beyond Design Basis, adequate analyses of these accidents need to be included in the chapter on Beyond Design Basis Accidents. In line with the conclusions of the assessment of the Primary Circuit Integrity, the data supporting the claimed **low probability for ruptures of large pipelines**, e.g. in-service metal inspection results, need to be included in the K1SAR.

In addition, some minor LOCAs are omitted but their omission is not justified. Each scenario should be discussed to explain why it needs no calculation, and why it is bounded by other analysed accidents.

The analysis of reactivity transients considers only two initial power states (100 % and 5 %), and there is inadequate justification in the K1SAR for the claims that the results from these analyses bound all cases, and that there is effective trip coverage at all power levels. A better demonstration should be provided that the selected reactivity accidents (choice of single rod, choice of control rod group, choice of power level) cover all potential scenarios.

There are no analysed cases of core-wide reactivity ramps with different gradients, e.g. due to an erroneous ramp of the reactor power set-point, or other such control or operator failure. The analysis of such reactivity ramps, no matter on what particular physical effect they are based, could show the response of the control and protection system on such ramps to rule out eventually hidden deficiencies.

In general, best-estimate calculations have been performed. Best-estimate calculations for Design Basis Accident analysis should always include uncertainty/sensitivity analysis, but there is none in the documentation. For the operational transients, uncertainty assessment is useful to quantify the margins. For LOCAs, uncertainty analysis is necessary, and should be performed and included in the K1SAR documentation.

The documentation of the **analysis results** is generally good. It allows confirmation that the single failure criterion has been applied consistently with regulatory requirements.

The documented results show that fuel damage occurs in only two of the LOCAs analysed, i.e. during full and partial rupture of a Group Distribution Header (GDH). The consequent radiation dose is higher than the permitted limit only in the case of partial rupture, which is considered to be BDBA on the grounds of very low probability. For transients the margins to fuel failure are large. Refuelling accidents do not pose a significant offsite threat because of the small amount of fuel and the low maximum temperatures involved. However the discussion of possible recovery strategies under high radiation levels in the reactor hall and the impact on plant personnel should be better presented in the K1SAR.

The analysis of Downcomer ruptures shows, unexpectedly, that the consequences of a single-ended break are worse than a double-ended break. This suggests that there might be a partial rupture (somewhere between 0 and 200%) that is still worse. This is already known

to be the case for GDH ruptures. However, analysis of partial ruptures has not been conducted for Downcomers or for other major pipework, e.g. Main Feed Water Line, Main Steam Line, and MCP Pressure and Suction Header. The reviewers understand that these will be addressed in a revised SAR.

The accident involving flow cessation in a high power fuel channel leads to both the cladding and pressure tube temperature criteria being exceeded with subsequent fuel and pressure tube failure. However, the off-site consequences are within the current regulatory norms.

The analysis of multiple pressure tubes ruptures shows, under conservative assumptions, that the Reactor Cavity venting capacity corresponds to five simultaneously ruptured tubes.

In the LOCA analysis, various trip parameters are claimed as providing alternative protection. The documentation does not include any demonstration that all the claimed parameters are in fact able to provide this protection. It must be shown, for each parameter singly, that its value would reach the trip set-point quickly enough to prevent violation of design basis limits, taking no credit for the other parameters.

The reviewers consider that Feed Water Line ruptures and Main Steam Line ruptures should be re-classified as DBA.

The analysis of offsite radiological consequences uses an inventory of radionuclides in the coolant based on operational experience, and lower than the maximum permitted by plant regulations. This means that the plant is allowed to operate under conditions worse than those assumed in the accident analysis, which the reviewers consider to be unacceptable. The radiological consequence analysis as a whole is considered to be conservative, but it should be based on the maximum permitted inventory of radio-nuclides in the coolant. This limit should in turn be based on a sound success criteria analysis, and the licensing basis should be updated accordingly. In general, a better justification of the analysis assumptions is required, including a quantification of the conservatism.

The K1SAR analysis of reactivity initiated accidents shows for all cases that safety parameters remain far below the limiting values given by the acceptance criteria. The main reason for the low values is early initiation of power reduction or reactor scram.

After modernisation, KuNPP-1 has a different core loading and control-rod configuration compared to that described and used in the K1SAR accident analysis. In addition, the new IICPS is installed now, featuring two independent shutdown sub-systems. The analysis of reactivity initiated accidents in the K1SAR, however, is not based on the current reactor core and plant configuration. The analysis needs to be revised to reflect the current configuration. The most punishing single failure should be systematically applied.

On the initiative of the K1IRSR Accident Analysis review team, a preliminary reactor trip coverage matrix was established by the Russian review team partners in consultation with the K1SAR authors. This matrix is intended to demonstrate for all initiating events as presented in the RF Guidelines, that there are at least two independent shutdown signals for each sub-system of the IICPS to protect the plant. This matrix is not complete yet. In many cases the assumptions and results used are preliminary since they are – in the absence of appropriate analysis – based on engineering judgement instead of extended analyses with computer codes, or on analyses performed for other RBMKs. Since limiting parameters may be reached very quickly in some accident sequences, precise computer analysis is needed to establish an improved matrix. Coupled thermal-hydraulics and 3D neutronics codes should be used where necessary. This matrix needs to be completed, and included in the K1SAR.

For ***Beyond Design Basis Accidents*** (BDBA) the K1SAR includes analysis of the following accidents of ATWS (Anticipated Transients Without Scram) type: Loss of main heat sink; partial loss of flow; loss of offsite power; loss of feed water; and control rod withdrawal at 100% and 5% power. The reactivity cases were analysed using STEPAN/KOBRA.

The analyses are generally well documented, with assumptions presented in sufficient detail. They show that the power stabilises without fuel damage in the partial loss of flow and control rod withdrawal cases, but that in the others severe core damage must be expected. The depth of analysis is generally sufficient, although the power oscillations observed in the “rod withdrawal at 5% power” case deserve further investigation, as does the analysis of simultaneous withdrawal of 4 rods. The reviewers understand that this will be addressed in the next update of the K1SAR.

The reviewers consider that these results underline the importance of having two independent shutdown systems. However there is no systematic trip coverage presented in the K1SAR, showing the effectiveness of the two systems at KuNPP-1.

Analysis of BDBA usually includes not only ATWS scenarios but also others such as station blackout. The results are used to help develop Accident Management measures, and the RF Guidelines include recommendations for such scenarios to be investigated. The reviewers agree with SEC NRS that, as a minimum, the scenarios listed in the Guidelines should be analysed in the K1SAR, and that other scenarios should be considered for inclusion.

4.5 Probabilistic Safety Assessment

The K1SAR documentation related to the Level 1 Probabilistic Safety Assessment (PSA) was assessed. The Level 1 PSA for KuNPP-1 was preliminary, so the absolute risk values from it cannot be used as justification of the safety of the plant.

The K1IRSR experts strongly support that an initiative be taken by Rosenergoatom on this issue, to fund a project aimed at carrying out a full scope PSA for KuNPP-1. This study, to be implemented according to the methodologies and standards currently applicable in Western countries, should complement the existing study and cover, in particular, the following issues:

- Utilisation of failure data specific to the real operation;
- Experience accumulated at KuNPP-1;
- Utilisation of a set of initiating events using the specific data from KuNPP-1 operation;
- Inclusion of alternative ways to mitigate some event trees for severe plant conditions;
- Consideration, at least of area events and, if possible, of external events.

4.6 Operational Safety

The review of *structural integrity and ageing of the primary circuit* focussed on the exclusion of failures of large pipes (800 mm diameter) on probabilistic grounds, the integrity of the primary circuit including Leak Before Break (LBB) arguments, leak detection measures and In Service Inspection (ISI) programmes.

The probabilistic fracture mechanics approach to evaluation of the frequency of rupture of the ferritic steel 800mm pipework is based on a sound methodology, but the low values of failure frequency need to be verified in the light of operational experience.

Although the integrity of the primary circuit components has not yet been fully demonstrated, it is evident from the numerous calculations reported to date that there is general compliance with the Russian design norms. Furthermore, it has previously been shown that the Russian design norms, and also the Russian defect assessment procedures, are generally

comparable with those of Western countries. Ageing and degradation phenomena appear to be under control, helped by the good quality of construction of the unit compared with others.

Leak detection measures are in place at KuNPP-1, but no formal LBB justification has been made for any of the large components. Consistent with other RBMK NPPs, LBB forms part of the safety justification for the Pressure Tubes of the Fuel Channels.

The current ISI programmes are in general adequate to support the safety justification. However, the ISI programmes being developed and carried out on KuNPP-1 primary circuit components have not all been formally qualified.

The presence of a **safety culture** framework was reflected in the procedures and policies at the plant. Elements contributing to a strong safety culture are visible in position descriptions, training documents, administrative procedures, programmatic procedures, audit processes, use of operational experience feedback and root cause evaluation methodology. Safety Culture is an element of REA safety policy document, as well as the plant's safety policy. The policy statement of the REA Director General states clearly the priority to be given to safety, and applies to all the NPPs.

Regarding root cause evaluation, the reviewers commend the manual developed by REA, while noting that the KuNPP regulation for Self-evaluation of Operational Safety does not always reflect that manual. The reviewers commend the lecture plan for Main Control Room (MCR) staff on Safety Assurance, but they note that such training is not given to all staff.

There is an effective process for exchange of incident and event information, which should maintain KuNPP current with all appropriate external sources of **operational experience feedback**. There is a similarly well-defined process to allow the use of internally developed incident information for positive reinforcement at KuNPP, and to make it available to others.

The **training** function appeared to be strong, in the process of implementing up-to-date processes, procedures and practices. The training interface with the production organisation is consistent with good current practice. There is a full-scale simulator for unit 4, and the differences from Unit 1 are compensated for by instructors.

The **interface** between operations and maintenance staff for conduct of maintenance work is structured and deliberate.

Equipment qualification (EQ) concerns the assessment of the vulnerability of equipment to internal and external natural and man-made hazards, and in particular to harsh environments and kinetic effects which may arise as a direct consequence of accidents (particularly pipe ruptures). The reviewers concluded that:

- The Russian regulatory framework includes sufficient requirements to define the basis of an effective EQ programme;
- Current KuNPP practice complies with these requirements, and provides the equivalent of a formal EQ programme.

The **radiation protection** programme at KuNPP is generally adequate in terms of breadth and effectiveness.

Measures for protecting personnel and population in the case of BDBA are contained in the plant **Emergency Preparedness** Plan (EPP). The EPP was designed according to the most recent Russian regulations, although it is based on a specific BDBA scenario which is not in the most recent list of such scenarios issued by GAN RF in 1997. The organisation set up by the plant to ensure the management of a BDBA and its consequences seems correctly designed and able to guarantee safety and evacuation of personnel in emergency conditions.

The reviewers observed a potential **fire hazard** from a room adjacent to the MCR. This raises the issue of fire spreading to other sensitive areas from adjacent, non-sensitive areas.

The **safety impact of internal events** (flooding, fire, projectiles, steam-flooding, heavy loads) is generally not reported in the K1SAR although this information does exist elsewhere. It is recommended that the safety impact of these events should be systematically discussed in the K1SAR for all safety-related systems or to refer to the supporting documents. These could include similar analyses performed for other RMBK plants.

The **Quality Assurance** Program at KuNPP appears to contain the key elements (and many desirable attributes) for assuring quality during the operational phase of KuNPP.

There are no human factor standards for preparation of **Emergency Operating Procedures** (EOPs), and hence no requirement for human factors to be taken into account in EOPs. There are no requirements for PSA development, and hence no requirement for consistency between the EOPs and the assumptions and results of the PSA (which would ensure that potential improvements in operational safety identified in the PSA are realised). A check on one specific example suggests that the assumptions on operator actions, made in the accident analysis as part of K1SAR, are consistent with the EOPs available to operators in the MCR. Training for existing (event based) EOPs is provided in both classroom and simulator. An activity is under way to establish Symptom Based EOPs.

Regarding the procedure for removing systems and equipment for **maintenance** and repair, responsibilities appear to be focused on scheduling and coordination of the work, work quality, and safe implementation, rather than on ensuring nuclear safety. This does not reflect the desired emphasis on nuclear safety as the prime concern.

Accident analyses for the **radioactive waste management** systems are not complete or are not presented in sufficient detail. Under normal conditions, releases into the atmosphere are small and have insignificant **radiological impact on the environment**. The liquid radioactive waste is stored in tanks with provisions to prevent releases into the environment in case of leakage of the tanks. The area/soil around these tanks is monitored. No processing of solid waste is carried out at present. Installations for this reprocessing are currently under construction. Also a storage facility for the solid waste is planned to be built.

5 CONCLUSIONS

The complete Summary Volume and a large amount of the supporting documentation of the K1SAR were studied by the K1IRSR team. The work has been valuable for all sides, promoting extensive dialogue on detailed issues of safety justification. It has been a good example of constructive co-operation between Russian and Western experts.

The K1SAR as a whole was written before the completion of the modernisation programme. The documentation contains a considerable amount of information covering most of the items that would be expected to be contained in a Western SAR. However it needs to be updated and improved in its structure and content. The reviewers noted some omissions and recommended that these be taken into account in future revision of the K1SAR.

The safety shortcomings of the original design of the first generation RBMK are well understood by Russian and international experts from this and earlier studies. The safety of Kursk Unit 1 has been greatly improved by a programme of engineering measures over the recent years, particularly by introducing diversity of emergency core cooling, and of reactor shutdown. In some cases, deficiencies in detail (either in the documentation, or by implication in the plant itself) have been observed and reported.

The basic principle for safety justification of the plant, which has been adopted by the utility, is endorsed by the K1IRSR reviewers. This is that:

- The plant should be compared with modern regulatory requirements,
- A programme of safety improvements should be adopted to eliminate deviations from the requirements wherever practicable,
- Where it is impossible or impracticable to eliminate the deviation, compensatory measures should be introduced to reduce the risk as much as possible.

This approach is in line with international practice provided that the improved state of the plant takes into account the need for sufficient defence-in-depth.

The important deviations from the current Russian regulations and the IAEA safety issues for RBMK are either fully resolved or are being addressed to the extent possible by compensatory measures to further reduce the risk.

Established practices and internationally recognized safety principles are found to be considered in the studies presented in the K1SAR.

On the basis of the review, the K1IRSR experts have made a number of recommendations for improvement of the K1SAR. They consider that the development of the K1SAR to keep it up to date with the state of the plant is an essential continuing process, and they have been reassured by discussions with the Russian Counterpart who clearly support this approach. The K1IRSR experts have been informed of many further analyses that have been carried out since the K1SAR [revision 2000] was written, which can be included in the next revision.

Rosenergoatom and KuNPP agreed on the review results and advice and explained that the revised K1SAR will consider the comments, findings and recommendations of the K1IRSR as well as the recommendations of the Russian Regulatory Review K1RSR.

All Russian and Western experts involved in the work are convinced that an extension of such cooperation to other NPP units elsewhere would be of benefit for nuclear safety.