INSTITUTE OF RISK RESEARCH
OF THE
ACADEMIC SENATE OF THE
UNIVERSITY OF VIENNA

Safety Relevant Issues and Measures: Khmelnitsky 2 and Rovno 4 NPPs

Updated Version

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Safety Relevant Issues and Measures: Khmelnitsky 2 and Rovno 4 NPPs

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Preface

This report was commissioned by the Austrian Ministry of Environment, Youth and Family to provide a technical assessment of the completion project of the NPPs Khmelnitsky unit 2 (K2) and Rovno unit 4 (R4). The main task was to treat highly relevant *safety issues* and to review and evaluate whether these are properly addressed. A second task was to determine whether adequate *measures* for solving problems concerning these safety issues are proposed within the frame of the completion project for K2/R4. In principle, the focus is mainly on *plausibility*, firstly regarding the completeness of issues, and secondly regarding the adequacy of corresponding measures.

The generally available *documentation* on the completion project of K2/R4 is very limited.[*] The Ukrainian K2/R4 Modernization Programme has not yet been released to the public. At present, the only published reports are the IAEA proposals for modernizing K2 and R4 which are based on the IAEA generic safety programme for WWER-1000/320 reactors. Riskaudit's revisions of the Modernization Programme, presented to TACIS, have also not been officially released for publication. A site-specific report by Riskaudit, which was announced for April 1997, is still unavailable. Further literature regarding similar WWER-1000 projects such as Stendal, Temelin, etc., is available.

The *methodology* for treating key safety relevant issues is based on the approach developed by the IAEA in the WWER-1000/320 generic safety programme. Due to the lack of site-specific information, these safety issues were mainly dealt with from a generic point of view.

The current report initially reviews all those issues ranked highest by the IAEA (with one exception) in their Modernization Programme for K2/R4. Special attention is given to a number of issues stemming both from the above IAEA programme as revised by Riskaudit, as well as from issues newly added by Riskaudit. According to Riskaudit's preliminary judgement, all may require extraordinarily expensive and time-consuming measures. The authors of the current IRR report felt obliged to extend the number of safety relevant areas and issues; a more detailed discussion on the extent of fulfillment of Post-TMI requirements is provided.

The *technical* possibilities of implementing safety measures are intimately connected with their *economic* feasibility. The strictly separated treatment of technical and economic issues, as prescribed to the evaluating experts of TACIS and EBRD, provides an incomplete picture of the full extent of the required effort. On one hand, insufficient knowledge of the economic constraints may lead to an overly optimistic view of a project's technical possibilities. On the other hand, poor information on the true extent of required technical upgrades may underestimate the funds needed to reach acceptable safety standards. The authors of the present study not only attempt to bear economic limitations in mind, but also draw attention to further

[*] As the distribution of some documents quoted is restricted, this study should be subject to the same restrictions.

important areas or issues such as the *infrastructural* and *logistic* preconditions of NPPs, *safety culture*, etc.; all are inseparably linked to technical safety issues.

The draft version of the report was reviewed in June 1997 by internationally renowned experts of Atomaudit, Kiev, with intimate knowledge of the Ukrainian situation. They basically confirmed the contents of the report but claimed that recent developments made some statements obsolete. Their comments on technical developments are included in the appropriate chapters; however, due to lack of documentation scientific evaluation was not possible. The legislative or political intentions they addressed are beyond the scope of this report.

A Tabular Summary incorporates various perspectives in order to provide a balanced overview of the current status of the K2/R4 completion project.

The study as a whole hopes to contribute to a more realistic judgement of overall technical and economic feasibility of the completion of K2/R4 NPPs.

Contents

Executive Summary

Introduction

The construction of Khmelnitsky 2 (K2) and Rovno 4 (R4) NPPs, both with WWER-1000/V-320s, was started in 1985/86 and stopped in 1990 as a result of a moratorium by the newly established Ukrainian parliament. The alleged completion levels are 70-80% for K2 and 80-85% for R4. Since cancellation of the moratorium in 1993, the intent has been to complete and modernize the units.

In a 1995 Memorandum of Understanding of G-7 countries and the European Commission with the Ukrainian government, a complete Chernobyl shut-down in the year 2000 against US$2.3bn compensation measures in the energy sector was agreed upon.

The main compensatory measure is intended to be completion and upgrading of K2 and R4 as replacement capacity. Financing is to be shared by EBRD (European Bank for Reconstruction and Development), EURATOM (each roughly 1/3), export loans and domestic money (each roughly 1/6).

A Project Management Group, which is a consortium of the "Kiev Institute" ENERGOPROJEKT in cooperation with, among others, the Russian organization MOHT[1] and experts of EDF (Electricite de France), developed an Ukrainian Modernization Programme for K2/R4. The overall objective of this programme is to reach an acceptable safety level comparable to the one achieved in Western NPPs erected during the same period. Shortcomings were identified and measures for upgradings proposed. The programme was evaluated by IAEA and Riskaudit, but not all recommendations of IAEA and Riskaudit for improvement have been adopted in the Modernization Programme.

Main Task of this Report

EBRD loans require that the submitted project meet "normal sound banking principles". In addition, the proposed project would need to satisfy EBRD's conditions for lending in the nuclear sector (as defined in its Energy Operations Policy):

- Be financially viable;
- Satisfy environmental and public consultation requirements;
- Satisfy western nuclear safety principles; and
- Be part of a least cost option.

[1] MOHT is an association of Russian organisations including: Atomenergoproject, OKG Gidropress, Kurchatov Institute, VNIIAES, Rosenergoatom, etc.

Similar conditions are required by the European Commission as far as EURATOM loans are concerned.

This report focuses on the third requirement for financing an EBRD project, the evaluation of whether the Ukrainian Modernization Programme for K2/R4 meets Western nuclear safety principles.

Highly relevant safety issues of K2 and R4 were identified and evaluated regarding whether these issues are properly addressed and whether adequate measures for solving problems concerning these issues are proposed within the framework of the Modernization Programme. The main results are presented in condensed form in the Tabular Summary.

The report also evaluated whether all safety improvements resulting from the analysis of the accident at the Western “Three Mile Island” NPP in 1979 are accounted for in the Modernization Programme for K2/R4 and the compliance of Russian safety regulations (on which the design of the WWER-1000/V-320 reactors and the safety up-grades are based) with Western safety codes and regulations is discussed.

The current IRR study, in contrast to earlier reviews, has also incorporated logistic and infrastructural points of view; the strong connection of these aspects to plant safety precludes an assessment relying mainly on technical issues.

The study is based on documents and data available by April 1997. The draft version of the report was reviewed in June 1997 by internationally renowned experts of Atomaudit, Kiev, with intimate knowledge of the Ukrainian situation. They basically confirmed the contents of the report but claimed that recent developments made some statements obsolete. Their comments on technical developments are included in the appropriate chapters; however, due to lack of documentation scientific evaluation was not possible. The legislative or political intentions they addressed are beyond the scope of this report.

Russian and Western Safety Regulations and Codes

Concerning the original design of K2 the IAEA stated *“The unit has a design elaborated in accordance with general rule OPB-73 and norms/standards being in force at that time. The design of the plant does not entirely comply with the current safety standards, and the GOSKOMATOM and Khmelnitsky NPP decided to introduce the modernization programme to upgrade the plant”*. The same was stated for R4.

The Russian safety regulations OPB-73 were updated to OPB-88 (“General Provisions for Ensuring Nuclear Power Plant Safety”) taking account of the lessons learned from accidents such as TMI and Chernobyl, the development of new safety methods such as PSA, and operational experience feedback. The differences between OPB-73 and OPB-88 are in areas such as safety culture, quality assurance of safety relevant components and systems, and advanced methods for safety assessment.

OPB-88 standards are the equivalent of the NUSS (Nuclear Safety Standards) of the IAEA, which represent the internationally accepted Western safety regulations in the sphere of nuclear power.

According to IAEA *“The analysis of the Russian NPP safety concept contained in OPB-88 and the next lower level Norms/Rules and its comparison with the NUSS requirements shows that while the concepts are the same, there are differences with respect to approaches and details.”*

In this context it is important to note that compliance with OPB-88 and therefore Western safety standards will only be reached by the generation following WWER-1000/V-320 reactor types. **The present WWER-1000/V-320 reactor type does not comply with OPB-88 in respect to important issues.**

Even in the upgraded form, **K2 and R4 will not fulfill OPB-88 - and therefore Western safety standards - in essential points**, as the analysis of the goals and scope of the planned Modernization Programme reveals.

Important Safety Relevant Issues

For WWER-1000/V-320 units in general, the IAEA identified safety issues only up to category III (out of IV), e. g. no unacceptable category IV aspects were found. Thus, WWER-1000/V-320s are considered to be reconstructible to a level *“satisfying Western safety principles”*.

The technical issues and necessary measures addressed in the Modernization Programme and related documents **focus on generic technical aspects** common to both projects. A major shortcoming of the proposed Modernization Programme is the fact that **site-specific issues** (such as Seismicity, External Hazards, Preservation and Mothballing, Nuclear Infrastructure, Safety Culture, etc.) are **rarely and not systematically included**.

Thirty important safety-related issues grouped in a dozen areas of infrastructure and technology were selected for closer consideration in this report. The performance quality of the **related measures** has a **strong impact** on the NPPs’ **safety**.

The areas are “Logistics, General, Core, Component Integrity, Systems, Instrumentation and Control, Electrical Power, Containment, Internal Hazards, External Hazards, Accident Analysis, Spent Fuel and Radioactive Waste”. An example for an important issue in the area General would be “Preservation and

Mothballing”, in the area Electrical Power “Residual Lifetime of Cables” and in the area Accident Analyses “Rapid Reactivity Increase”.

Only **twelve** of the above-mentioned thirty **important issues** were identified by IAEA and ranked III or II (below unacceptable category IV), implying that K2/R4 is reconstructible to a level satisfying Western safety principles.

Revision by Riskaudit revealed its preliminary judgement that the measures related to five of the above IAEA-issues may go beyond the schedule and budget limits of the K2/R4-completion project and identified **six additional issues** of this type not addressed by IAEA.

Twelve further issues (partially grouped in two additional areas: “Logistics” and “Spent Fuel & Radioactive Waste”), addressed neither by IAEA nor by Riskaudit, were added by IRR.

In this report the following safety-related technical issues and areas are considered to be not or insufficiently treated in the Modernization Programme: Preservation, Mothballing and Qualification of Equipment, Residual Life Time of Cables, Rapid Reactivity Increase, Man Induced External Hazards and Accident Analysis, Spent Fuel Storage and Radioactive Waste. The incomplete K2/R4-Modernization Programme is thus not a sound basis to satisfy Western safety principles.

The authors of the present study propose that in the case of the Ukraine, certain logistic issues deserve a higher priority than the commonly addressed issues dealing mainly with technical aspects. Unfortunately, following the common practice of the mainly technically oriented expert assessments (such as from IAEA, Ukrainian organizations and Riskaudit), infrastructural issues and logistic preconditions are not or only marginally addressed in the K2/R4-Modernization Programme. The outstanding importance of these issues was stressed, e. g. by the Kemeny Commission as a conclusion of their investigation of the TMI accident in 1979: The lesson learned from the above investigation is that an interdisciplinary approach is mandatory in this area. The Steinberg Commission, in re-investigating the causes of the Chernobyl accident before the political change in the former Soviet Union, arrived at similar conclusions.

Some infrastructural and logistic issues of special concern in the nuclear industry are related to the difficult economic and industrial situation in the Ukraine, to the loss of indispensable nuclear infrastructure due to the break-up of the former Soviet Union, or to the still insufficiently developed safety culture. This is reflected for example in the unsatisfactory performance of the already operating NPPs and the resignation of two recognized experts, G. Kopchinsky (vice-chairman) and N. Steinberg (chairman of the Ukrainian Nuclear Regulatory Authority), in late November 1993 and mid-December 1994, respectively.

These issues include some technical, but mainly economic, political and societal aspects; if at all, these frequently cannot be resolved by a set of simple measures

within a reasonably short time period and under tight budgetary constraints. The logistic issues in particular - as already demonstrated by the TMI and Chernobyl accidents - considerably influence nuclear safety and may partly be ranked in the highest IAEA category (IV: *not acceptable*).
If these preconditions for the Modernization Programme are not fulfilled at a satisfactory level, the entire project is questionable at least from the point of view of safety.

Spectrum of Possible Options for Completing K2/R4

The following two options mark the bounds of a spectrum of possible options for completion of WWER-1000/V-320s.

Option 1 *Completion with intensive Western funding and technology:*
Example - Temelin

Important preconditions for completing Temelin NPP are met much better than for K2 and R4: The construction work at Temelin has been continuous, and mothballing and preservation were therefore never a major issue at this site. The industrial environment as well as the financial situation in the Czech Republic cannot be compared with those in the Ukraine, and there is an intensive input of U.S. technology, equipment and financing.

Nevertheless, the Temelin project management is confronted with significant technical problems. Due to the complexity and the unique nature of the hybrid East-West design, a wide range of problems in redesigning and installing Western cable layout and I&C appeared; these remain unresolved despite almost three years of intensive effort. According to CEZ, Westinghouse seriously underestimated the scope of projects for Temelin upgrades.

These serious technical problems are reflected in time delays in the range of 2.5 to 5 years and cost overruns of US$1bn or more compared with the original estimates.

Option 2 *Completion without Western cooperation:*
Example - Zaporozhe 6

The Ukrainian Zaporozhe 6 (Z6), also a WWER-1000/V-320 type reactor, recently started operation (November 1995). With a history similar to K2 and R4, construction was frozen at an alleged 95% level of completeness, which was much higher than for K2 and R4. The infrastructure at the site - which counts 6 units and is the largest in Europe - was certainly superior to all other sites in the Ukraine.

Z6 was completed without Western funds and technical cooperation. In October 1995 it was granted a trial operation license, which expired in 1996. In 1997 the Ukrainian Nuclear Regulatory Authority (NRA) at first did not renew the operating license due to unresolved design problems. Recently the license was issued conditionally for one year.

Thus, neither of the two approaches are satisfactory from the safety point of view - quite aside from the economic aspect.

Conclusion

A number of technical issues argue against further pursuing the K2/R4 Modernization Programme. The important EBRD requirement that the project satisfy Western nuclear safety principles will not be fulfilled.

The vast number of issues and necessary measures in itself, which demonstrates the simplified approach to nuclear safety in the former USSR, cannot be solved with reasonable effort at this advanced stage of construction.

Important safety relevant issues are not or not properly addressed in the Modernization Programme. Even for some of the addressed safety issues, it remains unclear whether adequate measures can be found.

Beyond the technical safety aspects, the unfavorable infrastructural and logistic situation for nuclear technology theoretically do not permit further investment at the present time. Resolving these problems may be even more difficult than finding engineering solutions for technical shortcomings. Although a realistic estimate is beyond the scope of this study, the required funds and time will clearly by far exceed all projected limits.

Less risky energy saving or/and alternative power generation technologies should be considered.

Tabular Summary of Important Safety-Related Issues for K2/R4

The issues in the following table were selected due to their high relevance for safety and/or for financial and time efforts. The table lists 30 important safety-related issues grouped in 12 areas.[2]

Important Safety-Related Issues	Addressed in Ukrainian Modernization Programme	Comments
Area Logistics		
Economic Situation in the Ukrainian Energy Sector (IRR)	not	The economic situation in Ukraine is characterized by a deep crisis. No domestic funds are available for modernization projects in the energy system.
Nuclear Infrastructure (IRR)	not	After the disintegration of the USSR, an unsatisfactory situation exists in Ukraine.
Safety Culture (IRR)	not	The safety culture is generally insufficiently developed in Ukraine, especially on responsible levels of management.
Spare Parts (IRR)	not	The lack of spare parts is a problem which exists for the whole Ukrainian nuclear industry.
Fresh Fuel (IRR)	not	The lack of fresh fuel is a problem which exists for the whole Ukrainian

[2] **Twelve** of the thirty **important issues** were identified by IAEA and ranked III or II - below unacceptable category IV - implying that K2/R4 is reconstructible to a level satisfying Western safety principles (IAEA, 1996; IAEA-R4, 1995; IAEA-K2, 1997).

Revision by Riskaudit revealed that the measures related to five of the above IAEA-issues may go beyond the schedule and budget limits of the K2/R4-completion project and identified **six additional issues** of this type not addressed by IAEA (Riskaudit, 1996).

Twelve further issues (partially grouped in two additional areas: “Logistics” and “Spent Fuel & Radioactive Waste”), neither addressed by IAEA nor by Riskaudit, were added by the authors of the present study (IRR).

		nuclear industry.

Area General		
Preservation and Mothballing (IRR)	not	This issue is not yet sufficiently investigated. Strong indications exist for minimal or missing conservation/ mothballing of equipment and components, which might result in large cost overruns.
Qualification of Equipment (IAEA, Riskaudit)	partly	This task is still pending. Implementation has not yet been satisfactorily demonstrated.
Area Core		
Control Rod Insertion Reliability/Fuel Assembly Deformation (IAEA)	yes	This is a generic problem for WWER-1000/V-320s. It remains unresolved.*
Power Density Control System (Riskaudit)	partly	This is a TMI requirement which must be fulfilled.
Xe-Oscillations (Riskaudit)	partly	This is a generic issue, which is not yet resolved.
Area Component Integrity		
RPV Embrittlement and its Monitoring (IAEA)	yes	This problem is generic for all WWERs. Only limited solutions appear possible. Generally there is insufficient space for inspection of the RPV walls from the outer side on the level of the critical (highly irradiated) weld.
Non-Destructive Testing (IAEA)	yes	See above.
Steam Generator Collector Integrity (IAEA)	yes	This situation is insufficiently taken into account in the original WWER-1000/V-320 design. A design solution is still pending.**

* for Atomaudit´s comments see issue 3.3.1.
** for Atomaudit´s comments see issue 3.4.3.

Steam and Feedwater Piping Integrity (IAEA, Riskaudit)	yes	The integrity is impaired for all WWER-1000/V-320 reactors. Basic acceptable solutions are needed. Related measures might become cost intensive.
Area Systems		
ECCS Sump Screen Blockage (IAEA, Riskaudit)	yes	A solution for this problem is generally possible.
Steam Generator Safety and Relief Valves (IAEA, Riskaudit)	yes	This safety issue is generic. A satisfactory solution is generally possible.
Area Instrumentation & Control		
Reactor Vessel Head Leak Monitoring System (IAEA)	yes	This safety issue is generic for all WWER-1000/V-320 reactors. An adequate solution seems possible.
Area Electrical Power		
Emergency Battery Discharge Time (IAEA)	yes	Reliable solutions for this issue can be found.
Residual Life Time of Cables (Riskaudit)	not	This issue is not yet assessed. Corresponding measures might become cost intensive .
Area Containment		
Containment Bypass (IAEA)	yes	A satisfactory solution is limited due to the specific steam generator design used and its potential to fail.
Containment Structure (IRR)	not	Any deficiencies of the containment have thoroughly to be assessed and corrected.
Area Internal Hazards		
Fire Prevention (IAEA)	yes	The fire hazards potential and its prevention have not yet been sufficiently addressed in the modernization programme. A PSA is

		necessary to take effective measures.
Pipeline Breaks Impact Inside the Reactor Building (Riskaudit)	yes	Sufficient and reliable measures are still open.
High Energy Pipes Ruptures (Riskaudit)	partly	This is a safety issue applicable to all WWER-1000/V-320 reactors. Basic solutions to safely separate high energy pipes are still needed. Appropriate measures are potentially cost intensive.
Area External Hazards		
Extreme Weather Conditions: Low Temperature (Riskaudit)	partly	Assessing this issue will require performing a review of the design basis.
Man-induced external hazards and seismicity (IRR)	partly	This issue must be assessed in site-specific investigations, which have not yet been performed.
Area Accident Analysis		
Plant-specific PSA (IRR)	partly	The proposed modernization programme for K2/R4 is not based on plant-specific PSA results. Thus the possibility exists that measures are taken with unknown level of impact on plant safety.
Rapid Reactivity Increase (IRR)	not	A complete set of rod ejection analyses has to be accomplished for the start-up phase of operation of K2 and R4, taking into consideration the potential severity of this type of accident.
Area Spent Fuel and Radioactive Waste		
Spent Fuel Storage (IRR)	not	A critical situation with the spent fuel storage capacity can be expected by the year 2000.
Radioactive Waste Management (IRR)	not	There is a lack of a proper infrastructure for radioactive waste treatment and management in Ukraine

1 Introduction

1.1 Current Status of K2/R4

The construction of the NPPs Khmelnitsky unit 2 (K2) began in 1985 and Rovno unit 4 (R4) one year later (1986). For both units, reactors of the type WWER-1000/V-320 are foreseen (see Figure 1). Under the impression of the negative consequences of the Chernobyl accident and after gaining its independence, the Ukrainian parliament accepted in 1990 a moratorium on building and commissioning new nuclear power units. Construction work on K2 and R4 (as well as on all other nuclear units under construction) was stopped in 1990. Estimations for the level of completion of K2 are 70-80% and 80-85% for R4 (EC, 1994).

In 1993 the Ukrainian parliament canceled the moratorium and allowed the reconstruction of the frozen NPPs with WWER-1000 type reactors. Due to the lack of funds, however, reconstruction work - except on Zaporozhe unit 6 - has not yet been restarted.

In 1994, the European Commission (EC) - in accordance with the 1992 decision of the G-7 countries - developed an action plan for the Ukrainian energy sector which included the completion of K2/R4 with Western aid. After lengthy negotiations on December 20, 1995, the representatives of the G-7, the EC and the Ukrainian government signed a so-called Memorandum of Understanding (MoU).

According to this MoU, Ukraine commits itself to shut down all Chernobyl units by the year 2000, and the G-7/EC will provide funding in the framework of a cooperative program for compensation measures for the Chernobyl shutdown. However, the compensation measures in the energy sector must be proven to be the least cost option. The amount of financial aid under discussion is about US$2.3bn.

The main compensatory measure planned is to finance the completion and upgrading of K2 and R4, as a replacement capacity. According to European Bank for Reconstruction and Development (EBRD) statements, the completion costs for K2/R4 are on the order of US$1.2bn, which will be shared in the following manner: 38% (US$456mn) EURATOM credit, 31% (US$375mn) EBRD, 17% export loans and 15% Ukrainian government. Thirty months have been allotted for construction work, i. e. theoretically with completion in the year 2000.

Following the above development the Kiev Institute “Energoproject” was ordered by Goskomatom[3] to elaborate a “Modernization Programme for the Ukrainian Nuclear Power Plants with Reactors WWER-1000/V-320” to provide an engineering support for the Project Managing Group of K2/R4.

In London, at the EBRD, the project is currently in a status of internal revision. Two least cost studies have been performed, yet both lacked detailed information on the proposed technical upgradings of the “Modernization Programme”. In their 1995 study, Lahmeyer International GmbH (Germany) concluded that completing Zaporozhe 6 and K2/R4 would be the least cost option. In 1996 the Lahmeyer study was faced with various criticism. (CEE, 1996; Battelle, 1996)

The SPRU-team of the University of Sussex recently (Sussex, 1997) came to a contrary result. They concluded that:

“… K2/R4 are not economic. Completing these reactors would not represent the most productive use of $US1bn or more of EBRD/EU funds at this time.”

In April 1997, Stone&Webster Management concluded in their study that the completion of K2 and R4 is economic under their modeled future load scenarios (Stone&Webster, 1997).

In Brussels, the EURATOM share is currently being technically evaluated by the TACIS Expert Group. However, no cost information along with the Riskaudit assessment on the Ukrainian Modernization Programme was presented, nor was discussion on the costs issue permitted in the subsequent evaluation process.

To date, no detailed information on Environmental Impact Assessments (EIA) and on the Public Participation Procedure (PPP) is available.

1.2 Development of the K2/R4 Modernization Programme

According to Riskaudit (Riskaudit, 1996), the Ukrainian Modernization Programme was assembled with the engineering support of the Project Management Group ("Kiev Institute" ENERGOPROJEKT in cooperation with, among others, the Russian organization MOHT and EDF expert involvement).

The modernization programme has developed in a three-step approach. A revision 0 of the document has been prepared and commented by the Ukrainian Nuclear

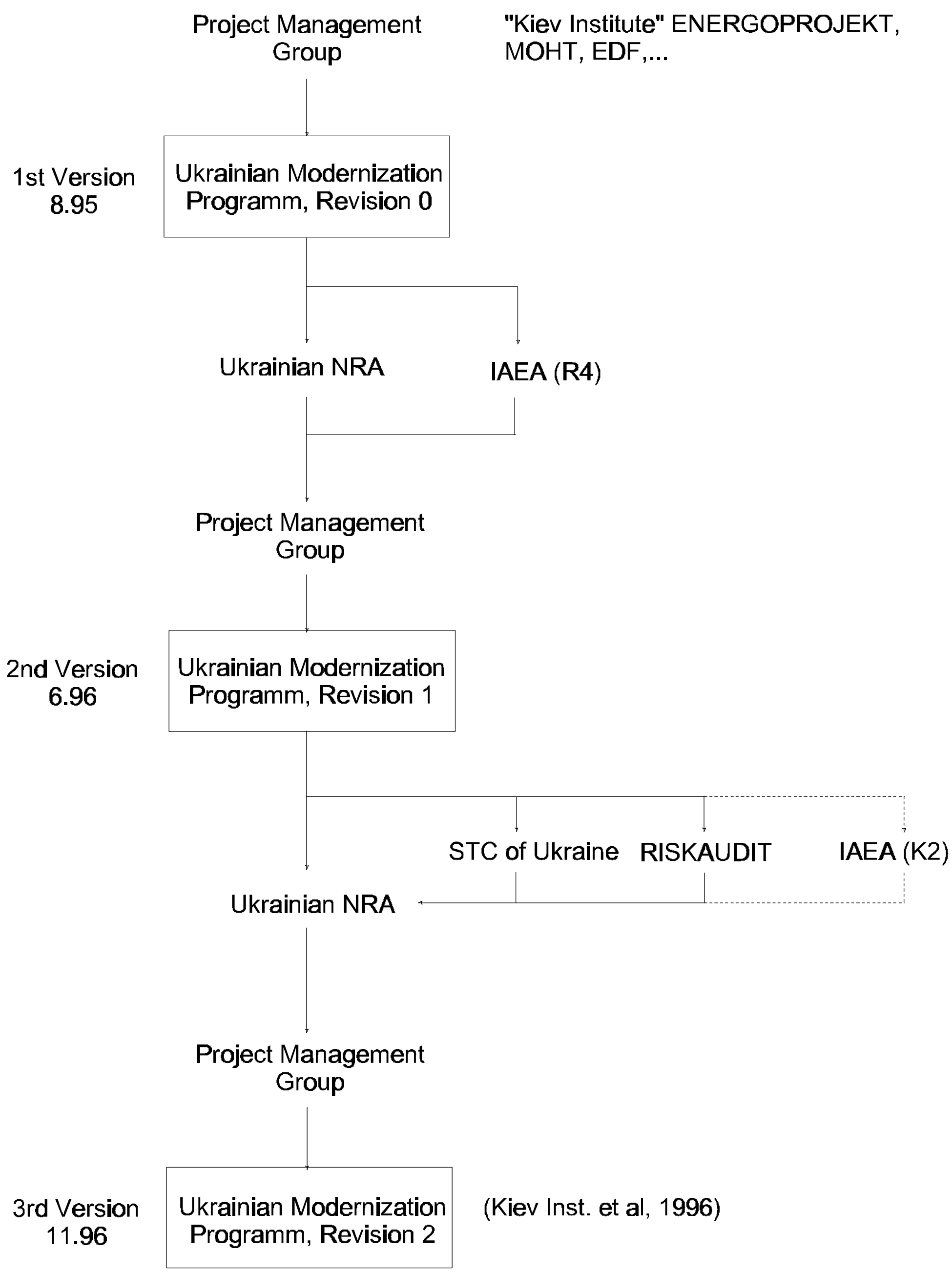
[3] The functions of the State Committee in charge of nuclear power plants (Goskomatom) have recently been transferred to the Department of Nuclear Energy within the Ministry of Energy of the Ukraine.

Regulatory Authority (NRA) as well as by the IAEA. On this basis, a more structured version (revision 1) has been prepared and submitted to the NRA in summer 1996.

This version has been rigorously evaluated for the NRA, firstly by the Ukrainian Scientific Technical Center on Nuclear and Radiation Safety (STC) in order to check the proposed version in view of the Ukrainian regulation and practice, and secondly by Riskaudit in order to check the proposed version in view of Western European practices, also taking into account internationally recognized documents such as the INSAG-3 (INSAG-3, 1988) and NUSS Codes of practice.

On this basis, the NRA has issued its official comments, which have been taken into account in the 3rd version of the programme (revision 2) issued in early November 1996 (Kiev Institute et al., 1996). See diagram below.

Developement of the Ukrainian Modernization Programme



1.3 Overview of the Objectives and Planned Measures of the K2/R4 Modernization Programme

According to Riskaudit's evaluation of the domestic project on the completion and modernization of K2 and R4 (Riskaudit, 1996) the **overall objective** is to reach an acceptable safety level comparable to the one achieved on Western NPPs erected during the same period.

On the assumption that the design safety philosophy and conception of WWER-1000/V-320 correspond to the modern safety principles (which in the opinion of IRR is questionable, see chapter 4.2), the proposed Ukrainian upgrading programmes do not intend to change the safety philosophy and conception or existing design basis.

The main goals of the modernization programme are to:

- eliminate the non-conformance with the current safety norms (Ukrainian regulation), having an impact on safety or to propose compensatory measures in order to reach an acceptable safety level, to
- improve reliability of safety-significant systems and equipment, and to
- implement the IAEA recommendations developed in the frame of the IAEA extra-budgetary programme on WWER-1000/V-320, in order to meet the international practice and experience.

The modernization programme consists of three parts:

- part 1 is a generic programme including all measures to be included for WWER-1000s (or already included for some of them) operating and under construction in Ukraine,
- part 2 presents the modernization programme to be implemented on K2 NPP, both before and after (i.e. 2-3 years) start-up,
- part 3 presents the modernization programme to be implemented in R4 NPP, both before and after (i.e. 2-3 years) start-up,

Parts 2 and 3 include the following:

- list (but also technical description) of the proposed measures,
- information on the improvement measures already implemented,
- information on safety improvement measures which will be (or are currently being) implemented within the frame of other programmes for Ukrainian WWER-1000 units (such as for example "generic" or "branch" programmes, operating organization plans for Rovno and Khmelnitsky NPPs)

- brief description of the status of implementation of measures and concise information on financial and planning needs. (This part is not a subject of the present review.)

All measures proposed in the modernization programme are classified in 3 groups:

- safety improvement measures
- reliability improvements
- operation improvements

Overall, the Ukrainian modernization programme includes 147 measures of which about half are devoted to improving safety (see Attachment 2).

An overview of the measures is given in the following table:[4]

Total number of measures	Including as follows							
	Safety Upgradings			Reliability Upgradings			Operation Improvements	
	Rank I	Rank II	Rank III	Rank I	Rank II	Rank III	Rank I	Rank II
147	**14**	**49**	**11**	**9**	**39**	**2**	**7**	**16**

[4] Ranking of Safety Upgradings according to IAEA (IAEA, 1996), ranking of Reliability Upgradings and Operation Improvements by authors of the Ukrainian Modernization Programme (Kiev Institute et al., 1996).

2 Ukrainian Situation

2.1 Overview on the Ukrainian Energy Sector

According to Kopchinsky et al. the installed electrical power capacity in Ukraine 1996 was shared in the following manner:

	Installed Capacity *(GWe)*	***Share*** *(%)*
Conventional	*37.1*	*65.5*
Hydro	*4.7*	*8.3*
Nuclear	*14.9*[5]	*26.2*
Total	*56.7*	*100*

"The total electricity production in 1995 was 194 TWh (6% hydro, 35.5% nuclear, 58.6% fossil (estimated at coal 29.7%, oil 4.5% and gas 24.4%)". "Electricity export was 2.8 TWh in 1995. 13.4 TWh was spent for own demand by power plants and 19.7 TWh was lost for electricity transmission. For end consumption was used 140.8 TWh. In 1995 industry and transport accounted for 49.5% of end electricity consumption, agriculture for 9%, commercial and public services for 14.8% and domestic consumer for 19%". (Kopchinsky et al., 1996)

Energy Demand

"Demand, particularly in heavy industry, has been falling as a result of severe economic recession and, according to international estimates, it is not expected to regain 1990-levels before 2010-2015,…". (Kopchinsky et al., 1996)

The experts of the Sussex group came to a similar result: *"Electricity demand has been so reduced by the highly depressed economic situation that there is a large capacity surplus which is likely to last until at least 2010. Installing further surplus generating capacity would use up limited borrowing authority for a purpose not needed and make it more difficult to achieve the efficiency objectives behind the Government's market-based reforms throughout the energy sector."* (Sussex, 1997)

[5] Including Chernobyl unit 2, which has not been in operation since the turbine hall fire in 1991.

Energy Efficiency[6]

Opportunities exist for substantial energy efficiency improvements in Ukrainian industry.

“Low energy efficiency in final uses and conversion processes, and high energy losses in electricity transmission and gas pipelines and district heating schemes, present an opportunity to improve overall productivity, reduce energy demand, and increase effective electricity supply capacity - all at relatively low cost.” (Sussex, 1997)

A number of improvements can be accomplished at very low costs, merely through good housekeeping. According to the existing assessments such measures can potentially save about 1600 MWe. The present studies show potential for energy saving in the short-term of at about 3000 MWe, with an average cost of US$ 0.01 per kWh saved (Sussex, 1997).

Some reasonably simple improvements could be made by installing variable speedmotor drives, process controls, efficient anodes, etc.; this could save approximately 900 MW (DOE et al., 1994).

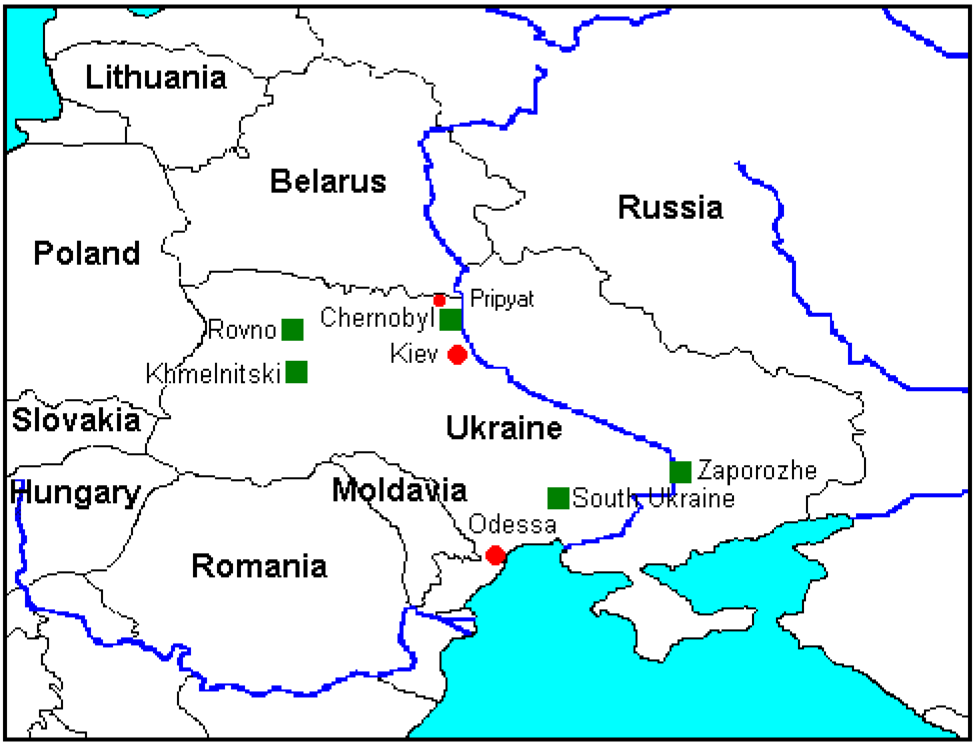
Grid Instabilities

“The possible reduction in electricity supply reliability threatens all sections (IRR: sectors) *of the economy. There have been problems stabilizing the grid at 50 Hz and Ukraine is disconnected with its neighbors grid due to instability of frequency in national electricity power net.”* (Kopchinsky et al., 1996)

[6] While Atomaudit in their review (Atomaudit, 1997) fully supported the statements on energy efficiency, they suggested the inclusion of a discussion of the fossil fuel option. The authors, however, considered this to be out of the scope of the present study.

2.2 Status of Ukrainian NPPs

Fourteen nuclear power units with a total gross installed capacity of 12,880 MWe are currently in operation in Ukraine. During the last few years they provided about 30 to 35% of the total electricity generation of the country. In 1996 the percentage rose to 44% (Atomaudit, 1997).



Operating units include two WWER-440/V-213 in the Rovno NPP and one RBMK-1000 at the Chernobyl NPP (unit 3). Eleven reactors of the WWER-1000 type are sited in four NPPs: six units in the Zaporozhe NPP (the largest NPP in Europe), one unit in the Khmelnitsky NPP, one unit in the Rovno NPP and three units in the South Ukraine NPP. The first two WWER-1000 reactors operating in Ukraine (at the South Ukraine NPP) are older versions. South Ukraine unit 1 is model V-30 and unit 2 is model V-338. All other WWER-1000 reactors are of the version V-320.

The most recent nuclear power reactor, Zaporozhe unit 6 (WWER-1000/V-320), started operation in November 1995. In the period 1990-1993, the construction of Zaporozhe 6 was frozen at a level of 95% of completeness. Afterwards, Zaporozhe unit 6 was completed without Western funds and technical cooperation. In October 1995, Zaporozhe 6 was granted a trial operation license, but it expired in 1996. Coincidentally, at exactly the same time, the reactor was shut down for refueling and maintenance. In 1997 the Ukrainian Nuclear Regulatory Authority (NRA) at first did not to renew the operating license for Zaporozhe 6 until maintenance on certain parts of the plant is completed to design. Recently a conditional license was issued for one year (Atomaudit, 1997).

Four more units with WWER-1000/V-320 - Khmelnitsky 2, 3 and 4, and Rovno 4 - are frozen in various phases of construction. The construction of South Ukraine unit 4 (about 10% completion) was canceled.

NPP Unit Number	Type of Reactor	Installed Capacity, MWe	Date of Commissioning	Duration of Operation+, Years
Rovno 1	WWER-440/213	402	12. 80	15
2	WWER-440/213	416	12. 81	14
3	WWER-1000/V-320	1000	12. 86	9
4	WWER-1000/V-320	1000	under construction	
Zaporozhe 1	WWER-1000/V-320	1000	10. 84	11
2	WWER-1000/V-320	1000	07. 85	10
3	WWER-1000/V-320	1000	12. 86	9
4	WWER-1000/V-320	1000	12. 87	8
5	WWER-1000/V-320	1000	08. 89	6
6	WWER-1000/V-320	1000	10. 95	10 months
Khmelnitsky 1	WWER-1000/V-320	1000	12. 87	8
2	WWER-1000/V-320	1000	under construction	
3	WWER-1000/V-320	1000	under construction	
4	WWER-1000/V-320	1000	under construction	
South Ukraine 1	WWER-1000/302	1000	12. 82	13
2	WWER-1000/338	1000	01. 85	11
3	WWER-1000/V-320	1000	09. 89	6
4	WWER-1000/V-320	1000	canceled	
Chernobyl 1*	RBMK-1000	1000	09. 77	18
2**	RBMK-1000	1000	12. 78	
3	RBMK-1000	1000	11. 81	14
4***	RBMK-1000	1000	12. 83	

+ at the beginning of 1996.
* shut down 1996.
** shut down after a fire in Oct. 1991.
*** destroyed during the accident in April 1986.

The RBMK-1000 reactor Chernobyl unit 2 was shut down in October 1991 after a harmful fire and its status is defined “as shutdown for further decommissioning”. However, it should be mentioned that in Ukraine there were discussions about possible restarting this unit in 1997-98. Due to the unresolved financial and safety problems, as well as to international pressure, this plan now seems unrealistic (at least regarding 1997).

Based on a decision of the Ukrainian president, Chernobyl unit 1 was shut down in 1996. However, the nuclear fuel is still loaded in the reactor core; from the technical point of view the restart of its operation is quite possible. Units 5 and 6 of the Chernobyl NPP, which were under construction at the time of the accident at Chernobyl unit 4 in 1986, are no longer under discussion. Therefore at the present time only Chernobyl unit 3 is in operation.

The national electricity supplier is the Ministry of Power and Electrification (Minenergo). The nuclear power plants are owned by Goskomatom[7] , which sells most of the generated electricity to Minenergo. The energy prices, however, are fixed by the Ministry of Economy.

The Ukrainian Nuclear Regulatory Authority (NRA), Ukrainian State Committee for Nuclear and Radiation Safety, was established in 1992. In 1994 a new NRA, Nuclear Safety Administration, was established as a part of the Ministry of Environment Protection and Nuclear Safety (Kopchinsky et al., 1996).

International Nuclear Conventions

In 1996 the Ukrainian government signed and parliament ratified the Vienna Convention on Civil Liability for Nuclear Damage.

The Nuclear Safety Convention was also signed by Ukraine, but has not yet been ratified by parliament.

[7] The functions of Goskomatom have recently been transferred to the Department of Nuclear Energy within the Ministry of Energy of the Ukraine.

2.3 Performance Indicators of the Ukrainian NPPs

During 1993-1995, the operational performance of Ukrainian NPPs was low. The Capacity Factor[8] (CF) for WWER-1000 reactors reached only 60.5 %, while the average world-wide CF is about 75 %. The operating statistics for Ukrainian WWER-1000 reactors are: for 1993 CF was 64.9 %, for 1994 CF was 59.4 % and for 1995 CF was 55.7 %, which are worse than statistics for Ukrainian RBMK-1000, WWER-440 (Sussex, 1997) and Western PWRs. Capacity factors in 1996 were in the same range (Atomaudit, 1997). The electrical output lost over the nine units of Zaporozhe and South Ukraine NPPs over the last few years was large (see table below).

Table of Capacity Factors of WWER-1000 reactors in Ukraine

Year	Z 1	Z 2	Z 3	Z 4	Z 5	Z 6	K 1	R 3	SU 1	SU 2	SU 3
1980											
1981											
1982									10.6		
1983									30.7		
1984									72.8		
1985	48.7	10.6							83.4	67.3	
1986	58.0	67.9	15.5						74.2	66.9	
1987	76.7	69.2	76.4	48.9			6.3	59.4	72.9	18.7	
1988	62.0	73.0	76.9	77.1			42.9	67.8	65.5	58.1	
1989	0.0	36.7	79.5	70.0	48.0		70.6	72.7	30.1	53.3	46.7
1990	56.1	22.5	67.6	79.8	56.2		78.1	76.4	74.2	21.3	68.4
1991	64.1	55.1	59.6	51.2	78.8		62.2	65.5	46.4	74.6	69.2
1992	73.1	78.5	49.6	79.3	78.5		72.8	80.7	67.6	73.0	73.5
1993	50.6	52.7	65.1	73.5	68.0		65.9	74.4	63.4	62.5	72.6
1994	45.3	49.3	51.4	70.8	58.4		75.7	67.0	61.5	47.6	66.9
1995	42.7	60.7	48.4	56.7	64.8	20.2	68.5	60.3	65.4	65.2	59.5
1992-1995	52.5	52.4	59.0	67.5	64.7	20.2	60.3	69.4	58.5	55.3	65.3
										Average:	**60.5***

* Excluding Zaporozhe 6 Source: IAEA, PRIS

Z…Zaporozhe, K…Khmelnitsky, R…Rovno, SU…South Ukraine

8 **Capacity Factor** - also called **Load Factor**: is calculated as the quantity of electrical output generated at the unit expressed as a percentage of the quantity of electrical output that would have been produced had it operated continuously at full design power rating.

There are a number of reasons for this poor performance:

- poor reliability of the equipment used,
- still insufficiently developed technical and safety culture,
- poor economic situation in Ukraine and lack of payment for the electricity supplied, decreased demand for electrical power due to the economic crisis, etc.

"The major reasons of not meeting the designed factors were ... excess repair downtime due to lack of materials and low quality of labor organization, emergency shut-downs and load decrease due to the various violations in the NPP's equipment and systems performance, deterioration of technical features of turbine condensers, etc." (Umanets, 1996).

"... the lack of QA programs and low level of safety culture at design and construction stages call for introduction of a number of safety improvement measures" (Smyshlyayev, 1996).

“The need for safety upgrades at the existing WWER-1000 stations is pressing. If the safety upgrades increase reliability, the extra output of the existing nuclear stations would make K2/R4 even more unnecessary. However, if the safety upgrades did not increase output, K2/R4 would be no more reliable than the existing WWERs with load factors around 60 per cent.” (Sussex, 1997).

3 Safety Issues and Measures for K2/R4

The IAEA ranks safety issues of NPPs in four categories, I to IV.

“Category I: Issues in Category I reflect a departure from recognized international practices. It may be appropriate to address them as part of the actions to resolve higher priority issues.

Category II: Issues in Category II are of safety concern. Defense in depth is degraded. Action is required to resolve the issue.

Category III: Issues in Category III are of high safety concern. Defense in depth is insufficient. Immediate corrective action is necessary. Interim measures might also be necessary.

Category IV: Issues in Category IV are of the highest safety concern. Defense in depth is unacceptable. Immediate action is required to overcome the issue. Compensatory measures have to be established until the safety problems are resolved.” (IAEA, 1996)

The concept of defense in depth which includes several levels of protection is defined in INSAG-3 (INSAG-3, 1988).

Only issues up to category III are reported for the projected Ukrainian K2/R4 units. Issues of category IV, which are of the highest safety concern, are generally not reported for WWER-1000s. This means that no unacceptable category IV aspects were found by the IAEA experts. Thus, according to IAEA experts, defense in depth concepts appear generally acceptable for K2/R4.

The following chapters mainly comprise K2/R4 safety measures related to issues of higher rank (category III) compiled by IAEA experts. The issues themselves are described in detail in the IAEA Modernization Programme for K2/R4 (IAEA-K2, 1997; IAEA-R4, 1995), see also Attachment 1.

Certain issues are complemented and additional ones are identified by Riskaudit.

The IRR provides additional comments on these issues and measures. It is important to note, that the study is based on documents and data available by April 1997.

The draft version of the report was reviewed in June 1997 by internationally renowned experts of Atomaudit, Kiev, with intimate knowledge of the Ukrainian situation. They basically confirmed the contents of the report but claimed that recent developments made some statements obsolete. Their comments on technical developments are included in the appropriate chapters; however, due to lack of documentation scientific evaluation was not possible. The legislative or political intentions they addressed are beyond the scope of this report.

3.1 Area: Logistics

A number of issues concern the infrastructural and logistic preconditions of NPPs. Besides technical, these issues include economic, political and societal aspects and, if at all, usually cannot be resolved by a set of relatively simple measures. They have a considerable influence on the nuclear safety and may be ranked even up to the highest category IV as *“not acceptable”*.

Exemplarily, the outstanding importance of the infrastructural and logistic preconditions for an NPP was stressed by the Kemeny Commission as a conclusion of their investigation of the TMI accident (Kemeny et al., 1979): *“To prevent nuclear accidents as serious as Three Mile Island, fundamental changes will be necessary in the organization, procedures, and practices— and above all—in the attitudes of the Nuclear Regulatory Commission and, to the extent that the institutions we investigated are typical, of the nuclear industry”* and *“When we say that the basic problems are people-related, we do not mean to limit this term to shortcomings of individual human beings—although those do exist. We mean more generally that the revealed problems with the “system” that manufactures, operates, and regulates nuclear power plants. There are structural problems in the various organizations, there are deficiencies in various processes, and there is a lack of communication among key individuals and groups.”* The lesson learned from the above investigation is that an interdisciplinary approach in this area is mandatory.

The Steinberg (Shteynberg) Commission, in re-investigating the causes of the Chernobyl accident before the political change in the former Soviet Union, stressed the importance of non-technical safety relevant issues: *“The system of legal, economic and sociopolitical correlations that existed prior to the accident and still exists in the field of nuclear power has no legal basis, and did not and does not meet the requirements of ensuring the safe utilization of nuclear power in the USSR. … As a result, there are dangerous facilities for which no one is responsible”*. (Shteynberg et al., 1991).

Following the common practice of the mainly technically oriented expert assessments (such as from the IAEA, Ukrainian organizations and Riskaudit), issues of this kind are not or only marginally addressed in the K2/R4-modernization programmes. Important issues in the area “Logistics” have been indicated by the IRR.

3.1.1 Issue: Economic Situation in the Ukrainian Energy Sector

Since 1989 the Ukrainian economy as a whole has gone through a deep recession. In 1995 the estimated level of real GDP was only 46% of the GDP in 1989. According to IEA data (IEA, 1996), gross industrial production fell by 42.1% in the three year period 1992 - 1994, while agricultural output fell by 23.8% and gross fixed investment by 72%. “*Further deterioration occurred in 1995 (until November): gross industrial production fell by a further 13.5 per cent; output of consumer goods by over 20 per cent; light industry by 34 per cent; engineering by 28 per cent; and food production by 14 per cent.”* (Chesshire, 1997)

Beyond this deep crisis in the overall economy, the energy system is confronted with specific problems. Non-payment or late payment of bills for electricity consumed is typical for Ukraine. All nuclear power plants continue to experience difficulties in obtaining payment for supplied electricity.

In January 1996 the National Electricity Distribution Center reported that about US$545mn remain unpaid (Kopchinsky et al., 1996). Due to high inflation (especially 1992-1993) and non-payment for supplied electricity, the Ukrainian nuclear sector is now in a critical situation. *“The situation in the nuclear power sector is aggravated by the extremely difficult economic and financial situation in Ukraine,…”*

Lack of money for purchasing spare parts and fresh fuel (see Chapter 3.1.4) as well as late payment of salaries for the NPP personnel are examples for the critical financial situation in the energy system. "*The nuclear sector is now in a critical situation due to non-payment for power, according to the State Committee for Utilization of Atomic Energy (Goskomatom)*....*As a result, Zaporozhe management cannot pay staff on time. In early July, Zaporozhe personnel held an unprecedented protest meeting in the nearby town, Energodar"* (NW, 1995c).

Comment (IRR)

In the above-described economic environment, large Ukrainian investments for modernization and maintenance measures in the power-generating system - especially in the nuclear sector - appear to be highly improbable. This pertains both to investments required in addition to the potentially approved loans as well as to loan repayments.

Furthermore, the poor economic situation does not encourage technicians, engineers and operators to fulfill the obligations expected of them by investors. Finally, the conditions are far from being motivating for current staff and future personnel. Thus, the poor overall economic situation has strong repercussions on plant safety.

3.1.2 Issue: Nuclear Infrastructure

The nuclear industrial complex of the former USSR was mainly concentrated in the Russian Republic. Because of the disintegration of the USSR the new independent states and the member states of the former Eastern bloc which operated their own NPPs were confronted with the loss of main designer organizations, architect engineer organizations, scientific institutions, as well as facilities for isotopic enrichment of the uranium and producing fresh fuel, spent fuel storage and reprocessing of spent fuel. Mainly due to political reasons, the previous system for cooperation in the nuclear field has become very restricted or been ruined altogether.

All Ukrainian NPPs were designed by scientific organizations concentrated in Russia: Gidropress, NIKIET, the Russian Research Center “Kurchatov Institute”, Atomenergoproject, VNIPIET, etc. Two small branches of Atomenergoproject are located in Kiev and Kharkov.

With the technical and financial support of the U.S. NRC, the governments as well as the regulatory bodies of Germany, France and Sweden, the Ukrainian Nuclear Regulatory Authority took concrete steps to organize its Scientific Technical Center (STC). This institution was founded in 1992 and its staff received training in safety institutions in the USA, France and Germany. STC was also supplied by computers and modern codes for accident analysis. However, the poor financial situation in Ukraine heavily damaged other scientific institutes like the Institute of Nuclear Research in Kiev and the Physical-Technical Institute in Kharkov, which have lost their most experienced scientists and engineers (Kopchinsky et al., 1996).

Ukraine has design organizations and facilities capable of manufacturing turbine generators, pumps, heat exchangers, tools, as well as electrical and electronic equipment. Ukraine is a supplier of raw uranium and raw zirconium. Several Western companies (Westinghouse Electric Corporation, ABB Combustion Engineering) attempted to form joint ventures with Ukrainian companies, but only a few of these attempts were successful.

Another important consideration is that after disintegration of the USSR, Ukrainian construction and installation organizations in the nuclear sphere dissipated and living conditions for Russian engineers and workers in Ukraine became increasingly difficult. During 1993-94 about 8,500 highly qualified specialists reportedly left for Russia.

"... Ukrainian salaries in general are only about one-tenth[9] *of what equivalent workers receive in Russia and resignations of qualified workers from Ukrainian nuclear plants*

[9] Smaller differences are quoted in other sources.

have increased two- or threefold in recent months. About 8,500 specialists have left for Russia over the past two years." (NW, 1995a)

As stated above, the disintegration of the former Soviet Union means that the Ukraine is also confronted with the loss of main designer organizations, architect engineer organizations and scientific institutions. The Soviet main designer organizations played a central role in completing and operating NPPs. Under normal conditions the main designer organizations took part in the supervision of NPP completion according basic design, in the supervision and evaluation of preoperational tests, and in the supervision and evaluation during the commissioning phase. Under emergency conditions they participated in supervising emergency situations, providing background information and possibly lost documentation, and accomplishing urgent research work.

In the U.S. system of regulations, active participation by the design and construction organizations in the licensing and operation of a nuclear power plant is a requirement. If another organization were to be substituted for the original design/construction partners, the utility would have to be able to demonstrate the qualification of all installed equipment to perform as required in an accident.

Comment (IRR)

In light of the above facts it can be predicted that reorganization of construction and installation companies for K2 and R4 will face major problems, ranging from difficulties in hiring experienced and qualified personnel up to lack of indispensable design background information.

One important precondition for completing K2/R4, whose fulfillment is necessary but still insufficient, is that the main designer organizations of K2 and R4 play the leading role in the projects. In the US, even comparably small changes such as replacing only the architect engineer and/or the constructor (the original main designer was never exchanged for any licensed NPPs in the US!) subsequently doubled the costs.

A further complication might result from the situation that only a limited nuclear industry is available in Ukraine. Most of the nuclear technology and engineering services must be imported from Russia and Western countries.

In summary, due to the lack of financial and industrial resources, the Ukrainian supporting infrastructure is not favorable for the further development of nuclear power.

3.1.3 Issue: Safety Culture

“Safety Culture” gained significant relevance after several nuclear accidents, especially the TMI and Chernobyl accidents. The growing consciousness about this problem revealed that safety culture must be cultivated on all levels of human activity in the nuclear area, beginning with the initial status of the project. Exemplary indicators of “safety culture” include quality assurance of work on safety-related equipment and components, quality assurance in the production of related materials, detailed and complete certification of these materials, thorough documentation and reporting of failures of the safety relevant products during tests and in service, accurate in-service inspection and its documentation, control of adequate repair of safety-related installations, adequate procedures and tools, as well as skilled and knowledgeable personnel for repair and replacement. These indicators have to be extended and applied to all safety relevant activities of persons connected with NPPs.

A number of reports (see below) stated that a lack of safety culture exists in the Ukrainian nuclear industry. A need for safety culture improvements is also addressed by the IAEA report on R4 (IAEA-R4, 1995):

“However, this is recognized as an area where much work remains to be done. Improved safety culture in operating units will also contribute to the improvement of safety culture in unit 4, which is under construction and where it is not yet possible to identify the results of the improved safety culture with respect to the contractors. “

"Regulator Nikolay Steinberg has identified the poor safety culture at Ukraine's plants as a barrier to good operation..." (Nuclear Engineering International, 1994). Unfortunately, in 1995 the world-renowned nuclear professional N. Steinberg (Shteynberg) was removed as Chairman of the Ukrainian Nuclear Regulatory Authority.

A specific Ukrainian feature is that the level of safety culture is higher among the plant operators and engineers than among decision-makers at the highest level of the governmental hierarchy, where the level of safety culture is very low (Kopchinsky et al., 1996). This is a direct consequence from the previous system in the former Soviet Union, where a number of organizations with high-ranking personnel were officially responsible for nuclear safety. After the Chernobyl accident, however, the entire responsibility for the accident was apparently suddenly shifted to the plant operators.

The problem of developing an understanding of safety culture continues to be still neglected or underestimated by plant managers and other high-ranking Ukrainian officials. A skeptical attitude towards the Western practice in creating safety culture can be observed for the personnel of Ukrainian plants (Kopchinsky et al., 1996). The fact that this is also valid for the government authorities is an important shortcoming.

The reported exchange of almost 90% of the Chernobyl NPP personnel in 1988-89 (Tolstonogov, 1996) is an unprecedented example of poor safety culture at the highest level; continued operation of the plant with inexperienced and poorly trained personnel led to an increase in the rate of violations and to a major fire in October 1991 in the unit 2 turbine hall.

Lack of sufficient safety culture is one of the reasons for the relatively high number of emergency scrams in Ukrainian NPPs *"..the number of variously caused emergency shutdowns of Ukrainian NPP units - 32 cases in 1995 as opposed to 34 cases in 1994"* (Smyshlyayev, 1996).

A deficit of experienced and well-trained operational and maintenance personnel with a well-developed safety culture for the considered nuclear units has to be expected (The staff of one power unit with a WWER-1000 type reactor is about 1000 persons. In comparison, the staff for the German NPP Isar-1 and Isar-2 is about 700 persons) (IAEA-R4, 1995).

Comment (IRR)

An adequate safety culture is an indispensable and mandatory prerequisite for reaching a sufficient safety level in the power-generating nuclear industry. Maximum attention should be given to the completeness, the establishment and implementation of a special safety culture program for all contractors involved in the possible construction of K2 and R4.

Note that safety culture programs do not in themselves represent safety culture. Such programs are merely the initiation of a process which has to be taken over by knowledgeable, well-educated and prepared, and highly motivated persons. The lack of such persons in Ukraine is in part the result of their poor income due to the critical economic situation in the country.

The success of safety culture programs is hindered by the difficulties of involved persons to change their traditional attitude to nuclear safety.

3.1.4 Issue: Spare Parts

After disintegration of the Soviet Union the new independent states were confronted with the fact that most facilities manufacturing equipment and spare parts for nuclear power plants are in Russia. The successful operation of Ukrainian NPPs is therefore highly dependent on delivery of equipment and spare parts from Russia.

Due to the economic crisis in Ukraine, lack of money in the nuclear industry, and the inflation rate, all Ukrainian plants suffered unresolved problems with the delivery of spare parts. For units which went into operation in the early 1980s, the design life of the original Russian I&C (10 years) expired. This results in an increased failure rate, including relay contact oxidation and low insulation resistance of wiring and terminals. The operating nuclear plants have limited possibilities even to replace degraded equipment. "*At present 20% of valves and 70% of other components in the plants are in need of replacement, the committee says"* (NW, 1995c). A lack of important but expensive diagnostic equipment, manufactured in Western countries, is also reported (Kopchinsky et al., 1996). These problems result in the poor condition of equipment and in an insufficient quality of maintenance and repair.

Under these circumstances it can be expected that some of the equipment delivered to units under construction has been used in operating units.

It should be mentioned that one of the main concerns of the European Union's TACIS program is the problem of spare parts for NPPs in Russia and Ukraine, particularly for those plants which have installed Western equipment. The EU has set up a special budget to purchase and deliver these parts (Phare/Tacis, 1996).

Comment (IRR)

The unresolved problems with the delivery of spare parts and replacement of degraded equipment, as well as with the poor quality of the fresh nuclear fuel elements (see also next issue), will complicate the process of reconstruction and commissioning of R4 and K2 and could create major uncertainties in evaluating unit reliability and safety.

A related comment of the Sussex-report see issue 3.1.5.

3.1.5 Issue: Fresh Fuel

To date, Russia is the only manufacturer of fresh nuclear fuel for WWERs and RBMK. In addition to equipment and spare parts, the successful operation of Ukrainian NPPs is therefore also highly dependent on the delivery of nuclear fuel from Russia.

The reported lack of financing available to the nuclear industry also resulted in problems with payment and delivery of fresh nuclear fuel from Russia. Reportedly, the practice of "fuel economization[10]" through coast-down mode operation in the end of the cycles (sliding power level, controlled by the status of the core itself, resulting in additional reactivity for increased fuel burn up), or operating the units at reduced power level during the summer period, often took place in operating nuclear units. Due to the lack of manufacturing technology for movable burnable absorbers, or neutron absorbers integrated in the fuel pellets, as well as due to the fixed enrichment of the fresh fuel, the operators cannot adjust the cycle's duration. The result is worsening of performance indicators of Ukrainian plants.

[10] This expression is often used for a forced and economically non-viable extension of the fuel cycle duration of WWER-1000s.

A common practice in Western NPPs is to use a neutron source in the core to enhance the neutron flux level during the reactor shutdown or startup phase. However, Russian fuel assemblies are not designed to meet this requirement.

The Russian-designed cluster control rods use B_4C as neutron absorbing material. However, the service life of 1 year for regulating, and 5 years for shutdown rods is considerably less than for other kinds of absorbers. In comparison, Ag-In-Cd absorbing material used in Western plants has a service life of 15 years. An additional safety concern is that control rod efficiency is lower than in a typical Western plant.

NPPs were also hampered by a poor design of the supplied fresh fuel elements, which in conjunction with the big axial forces led to stuck control rod problems at almost all WWER-1000 units. For units under construction, the proposal has been put forward to replace the protective tube unit of reactors in order to overcome this obstacle.

Comment (IRR)

The problems with the poor design of the fresh nuclear fuel elements as well as with the fuel delivery itself will further complicate the process of reconstructing and commissioning R4/K2 and the subsequent operation; it will also create uncertainties in evaluating the units' reliability and safety.

According to Sussex, the only possible measure to solve these problems is:*"…Meanwhile, provided that all consumers resume paying their bills and electricity prices cover full costs on a continuing basis, electric utilities will have the money to buy sufficient fuel and spare parts."* (Sussex, 1997).

As a side aspects, it should be noted, that one of the common arguments against fossil power plants - dependence on imported fuel - is far more valid for nuclear power.

3.2 Area: General

The IRR has added the following issue “Preservation and Mothballing” to the category III list due to its strong influence on the success of corresponding measures for safety improvement. The issue also plays a key role for the safety of NPPs under normal and emergency conditions and during several sensitive phases such as start-up phase, trial operation phase and commissioning phase.

3.2.1 Issue: Preservation and Mothballing

One of the most important general safety-relevant problems for K2/R4 is that at least during 1990-1993 conservation and mothballing were marginal, or not accomplished at all, because of the moratorium. The economic crisis in Ukraine, lack of money in the nuclear industry and high inflation rate during this period exacerbated the problem. During the moratorium, responsibility for handling problems of the unfinished units was transferred to the managers of the nuclear plants.

While the Zaporozhe NPP in Ukraine already had 5 units in operation, a great number of experienced personnel, a decisive manager, and some financial leeway to conserve the equipment and even to continue construction work, this was not the case for the other NPPs under construction.

Any comparisons concerning mothballing with Temelin NPP units are inappropriate because construction work at Temelin has been continuous: preservation and mothballing were never a major issue at this site.

A great degree of uncertainty about the status of components, equipment and buildings of K2 and R4 has to be expected. An important fact is that the manufacturers’ guarantees for already delivered equipment have expired. At the time of construction of K2 and R4 the Russian manufacturers’ guarantees commonly ended after a few years. The quality of construction work is largely unknown and documentation is very poor (Kopchinsky et al., 1996). According to the latest information evaluation of the status of equipment has begun (Atomaudit, 1997). Results are not yet available.

Even the Ukrainian nuclear operating organization, Goskomatom, in its application for funding for the completion of K2 and R4, recognized that:

“... It should, however, be noted that the equipment was not adequately protected on Khmelnitsky 2 subsequent to the complete stoppage of work owing to the moratorium on nuclear energy“ and *“... However, if we take into account of the possibility that electrical safety equipment may not be re-qualified by the*

manufacturers (argument put forward by the correspondents met at the plant - it should also [be] noted that this plant suffered flooding during the moratorium), then the extent of completion would be similar to that of Rovno, complicated by the problems of disassembling equipment and removing the existing electrical cables". (Goskomatom, 1995)

Concerning the state of the already existing, erected parts, Riskaudit noted that the quality of the installation has not yet been examined. However, they consider their present advice to be valid only if the quality is satisfactory. Furthermore, the qualification of those components called to operate under accidental conditions depends on a Ukrainian generic safety program which remains to be developed, much less implemented. Again, Riskaudit considers its conclusions to be valid only if the qualification of existing components proves to be satisfactory. They state that the specific evaluation of the generic program is slated for spring 1997, when the corresponding report will be available for review. Riskaudit has announced a specific report on this key issue.[11]

Finally, Riskaudit concludes that implementing the modernization and complementary programs would allow plant safety to be adequate with Western and international safety principles and practices - but only under two conditions:

1) that the qualification issues for existing equipment be properly solved by the implementation of an as yet unfinished branch program, and
2) that no uncorrectable safety concerns be identified in the ongoing review of quality status (Riskaudit, 1996).

IAEA experts who visited Ukraine also expressed concerns about the status of the equipment:

"…Taking into consideration the long construction and moratorium periods, the status of the electrical equipment already in place and of the electrical system rooms need to be further assessed, corrected and protected on a continuous basis. Parts of the equipment of the emergency power systems have reached the end of their design lifetime, e.g. inverters, rectifiers and batteries. Other equipment, such as the 6 kV and 0,4 kV switches, have construction deficiencies that lead to failures. To a large extent, the failures of cables are caused by insulation aging and impacts during the long construction time. This is brought about by the physiochemical process occurring under adverse environmental or mechanical conditions. The sealed cable penetrations (through containment wall penetration) show deterioration of insulation caused by humidity. Due to the insufficient tightness of the sealed cable penetrations, the containment tightness decreases." (IAEA-R4, 1995)

Experts from the University of Sussex also focused on the deterioration of the equipment in the two discussed units:

[11] This "site-specific" Riskaudit report is still not available.

"*A major issue for the completion of K2/R4 is the condition of storage of the plants in the 8 years that construction work has been suspended. Goskomatom reported deterioration at Khmelnitsky while an International Atomic Energy Agency (IAEA) inspection identified concern about the condition of equipment at Rovno. If substantial remedial work is required, this could lead to significant unanticipated additional costs being incurred".* (Sussex, 1997)

Significant funds are needed to check and evaluate the state of equipment and to replace the damaged parts. According to the assessments (DOE et al., 1994), at least US$67mn for K2 and US$19mn for R4 have to be planned for "*moratorium-related expenses"*.

Comment (IRR)

Without detailed information on the true extent of degradation, adequate measures cannot be formulated (see IAEA-K2, 1997; IAEA-R4, 1995; Riskaudit, 1996).

From this point of view the estimated costs and completion time for the K2/R4 project are questionable because the basis for the estimation is incomplete. These estimations must be judged as too small. A thorough evaluation of the status of the equipment has to be performed in order to provide a sound basis for cost and time estimations. This sound basis is still missing.

Unknown and unpredictable difficulties can be expected in the process of checking the degradation level of installed equipment. The possibilities to check certain equipment, cables, constructions, and check for the presence of hidden defects, etc. will be reduced. Because of the reported restricted funds in the Ukrainian nuclear industry, uncertainties will occur in the results from the field tests of equipment. It is also questionable whether all parts of damaged or degraded equipment will be replaced. Thus, higher rates of equipment failure during the start-up phase and initial operation have to be expected, which could have a very negative effect on plant reliability and safety.

From the above point of view the following issue "Qualification of equipment" is of high importance.

3.2.2 Issue: Qualification of Equipment

The proposed IAEA measures include:

- qualification of SG safety valves, pressurizer safety valves, and BRU-A for operation with water and steam-water mixtures;
- provision of seismic resistance for certain types of ventilation equipment which

are part of the safety support systems, fire detection sensors and service water pumps; and

- confirmation of serviceability of some types of electrical equipment and I&C components under emergency environmental conditions.

Conclusions and Recommendations (IAEA)

- The safety issue has been addressed. Work should continue to resolve the remaining noncompliances.

In addition,

- The adequacy of the qualification of the safety-related equipment should be assessed by the regulatory body.
- The remaining qualification problems should be resolved and work on cable qualification should continue.
- The functionality of the ventilation systems to guarantee the required environmental conditions for safety systems under accidental conditions should be analyzed.

Recommendation (Riskaudit)

Riskaudit has also identified this issue and recommends a “Branch Programme for Accidental Qualification of Existing Equipment”. According to their preliminary judgement, this issue potentially requires extraordinarily time-consuming and/or expensive measures and should be implemented after start-up of K2/R4 (Riskaudit, 1996).

This measure is partly addressed in the Ukrainian Modernization Programme (Kiev Institute et al., 1996).

Comment (IRR)

Equipment qualification appears to be a critical path on the way to complete the K2/R4 NPPs. Unknown difficulties can be expected due to the unsatisfactory mothballing and conservation situation. This might also lead to higher costs within this area.

In qualifying equipment, the categories safety-related and non-safety-related have to be thoroughly identified. Qualification of safety-related equipment must be performed in any case *before start-up* of the reactor. Thus, IRR cannot follow in general the Riskaudit recommendation on implementing a “Branch Programme for Accidental Qualification of Existing Equipment” *after start-up* of K2 and R4. IRR can only agree with this recommendation in the case of non-safety-related equipment.

It is mandatory that impaired safety equipment be replaced rigorously. This process must be strictly observed by an independent licensing authority.

3.3 Area: Core

It is well known since 1992 that WWER-1000/V-320 reactors have problems with control rod insertion reliability. An increase in the rod drop times was observed. On occasion, a control rod remained stuck in the core. Thus, power control and shut down capability was impaired due to failure of the control rod mechanism.

The Russian-designed and -manufactured power and neutron distribution control system is of an old design. The power level does not automatically decrease when picking factors are above limits. No system automatically suppresses Xe-oscillations. Russian technology for manufacturing fuel pellets and assemblies still does not involve movable burnable absorbers, neutron absorbers incorporated in the fuel pellets, updated absorbing materials for control rods, etc.

3.3.1 Issue: Control Rod Insertion Reliability / Fuel Assembly Deformation

The proposed IAEA measures include:

- modification and readjustment of the protective tube unit to reduce the axial force exerted on the fuel assemblies as a compensatory measure;
- determination of the extent of distortion of the guide tubes in order to estimate the power density increase due to the change in gaps between the adjacent fuel assemblies; and
- assessment of the effect of fuel assembly deformation on the control rod drop time under condition of the most severe design basis accident combined with safe shutdown earthquake. This issue is planned to be studied in relation to the effect of additional mechanical loads on the control rods.
- use of heavier control rods to help increase the drop time.

Conclusions and Recommendations (IAEA)

The control rod insertion problem is a generic safety issue for the operating WWER-1000/V-320 reactors. It is recommended that the operational performance of control rod insertion be carefully followed and that the supplier and user group investigations of the root cause leading to the permanent bowing of the fuel assemblies, which increases the friction between rodlets and guide tubes, be supported. The maximum permissible deformation of the fuel assembly should be established in order to ensure that the increase in power density remains within the design limit. Additional analyses of the mechanical stability of the degraded fuel assemblies under the LOCA and/or seismic conditions need to be performed. Based on the results of root cause analyses, future consideration should be given to improving fuel assemblies.

Comment (IRR)

Maintaining reliable power control capability under all normal and emergency operating conditions is an issue of highest safety relevance. The control rods are designed to control the power in the reactor core under all operating conditions. The reliable function of this safety relevant system requires a reliable and resistant mechanism for safely operating the control rods.

It is astounding that “Control Rod Insertion Reliability/Fuel Assembly Deformation”, which is a generic safety issue of the WWER-1000/V-320 control rod mechanism, has apparently not yet been resolved. The root causes for the failure in several Eastern plants still remain to be identified.

Contrary to the IAEA assessment (IAEA-K2,1997) Atomaudit claims that the reasons for control rod jamming have been clarified and measures to eliminate them have been developed and implemented in all working units (Atomaudit, 1997). However, it was not possible to verify this information on the basis of related documents.

Among other difficulties, the fact that problems with power control have remained unresolved for so long can be taken as a strong indicator for a lack of specific expertise in the involved countries; this situation appears to be aggravated by the disintegration of the Eastern system.

3.3.2 Issue: Power Density Control System

According to a preliminary judgement by Riskaudit, this issue potentially requires extraordinarily time-consuming and/or expensive measures, which are under development and will be implemented after start-up of K2 and R4.

Measure (Riskaudit)

Implementation of an automatic power density control system.

Comment (IRR)

This issue is partly addressed in the Ukrainian Modernization Programme (Kiev Institute et al., 1996). At least since the accident at Three Mile Island in 1979 this issue is of high importance; it is also related to the Xe-oscillations that have occurred in the core of several WWER-1000/V-320s. The original Russian design of the in-core measurement system had no automatic control mechanism to prevent adverse power distribution. To date only administrative procedures and manual operations are available. According to Riskaudit the potentially very expensive and/or time-consuming measure will be implemented after start-up. The fact that such a measure it is not the practice for Soviet-designed units operating in base load mode may decrease the priority for timely implementation

3.3.3 Issue: Xe-Oscillations

According to a preliminary judgement by Riskaudit, this issue potentially requires extraordinarily time-consuming and/or expensive measures; they should be implemented after demonstration of availability, verification of procedures and performance of qualification tests (i.e. after start-up of K2 and R4).

Measure (Riskaudit)

Installation of equipment for automatic suppression of Xe-oscillations.

Comment (IRR)

Xe-oscillations of power density are a typical phenomenon for large reactor cores. They could disturb neutron flux and power distribution, resulting in picking factors far above limits. WWER-1000 is the first large Russian-designed reactor of this type. Lack of experience along with outdated hardware and computer codes are the main reasons for the lack of equipment that can automatically suppress Xe-oscillations in operating units, forcing operators to control them manually.

This measure is partly addressed in the Ukrainian Modernization Programme (Kiev Institute et al., 1996).

3.4 Area: Component Integrity

Reactor pressure vessel embrittlement is a generic problem of pressurized water reactors. However, it is enhanced in Russian WWERs due to

- a relative small downcomer water/steel gap between pressure vessel wall and core periphery region (see Figure 4).
- and a higher Ni concentration in vessel beltline area welds (see Figure 5).

Surveillance specimens for monitoring progress of embrittlement are an essential tool to monitor this process.

The reactor vessel wall is part of the primary circuit boundary which is the third physical barrier. It thus represents part of the last solid barrier before the containment, which is the final barrier to the atmosphere in the event of a Large Break LOCA .

Pressure vessel integrity is also required in the event of an LB-LOCA of the primary loops. In this case the pressure vessel represents the coolant container for residual heat removal from the still heated reactor core. Thus, maintaining the integrity of the pressure vessel is mandatory in order to contain radioactive material and to maintain coolability of the reactor core.

3.4.1 Issue: RPV Embrittlement and Its Monitoring

The IAEA measure proposed includes the development of a standard system for continuous monitoring of the fluence in order to estimate the residual life of the reactor vessel.

The measure proposed focuses on decreasing the fluence of neutrons on the reactor vessel by introducing a low-leakage reloading pattern.

The measures proposed include the technical solutions to ensure that the water supply to the RPV from ECCS pumps does not have a temperature lower than 20°C and that the water supply from ECCS hydraulic tanks is not colder than 55°C.

The measure proposed includes the establishment of correlations between the surveillance specimen conditions and vessel wall conditions.

The measure proposed includes the development and introduction of a new surveillance programme (specimen not located on the reactor vessel wall) in order to

meet the PNAEG-7-008-89 requirements.
The measure proposed includes the development and application of approved methods for radiation damage assessment of the RPV with respect to fluence accumulation, including dosimetry measurement at actual RPV of WWER-1000 units, mock-up and surveillance programme results.

The measures proposed define the residual lifetime of a pressure vessel due to radiation damage .

The measure proposed includes the performance of RPV thermal stress calculations.

Comment (IRR)

High pressure vessel embrittlement is already a specific concern with the oldest generation of WWER reactors originating in the 1950s. Thus, it is astounding that this is an ongoing problem in the latest generation of WWERs. The welds were made with material having a higher Ni content. Because of this element in the welds irradiation embrittlement takes place faster than anticipated. The records already available and data from the oldest WWERs apparently have not led to significant improvements, neither of the weld material used for critical welds nor of the location of the welds in relation to the reactor core.

Non-destructive testing of the reactor coolant system boundary is state-of-the-art in modern NPPs. The Russian approach in this area was more or less an industrial one up to the latest WWERs. In some cases insufficient space is foreseen for the inspection of critical areas of components functioning as radiation barriers. This fact give rise to problems with integral, consistent and reliable verification of the status of the material used in these areas.

3.4.2 Issue: Non-Destructive Testing

The IAEA measure proposed includes the application of the Leak Before Break (LBB) concept on primary and secondary circuits.

The following proposed measures include the development and implementation of:

- an in-core noise diagnostic system;
- a system for diagnostics of air-operated valves;
- a system for diagnostics of check valves;
- an industrial television system inside the containment;

- a system for reactor vessel in-service internal inspection;
- an operational diagnostic system;
- methods of processing the diagnostic information;
- a vibration diagnostic system for the reactor facility ,
- a loose part and inadequate fixing detection system;
- noise diagnostic systems for SG headers and other equipment;
- a primary circuit leakage detection system;
- a residual fatigue lifetime diagnostic system;
- a main circulation pump vibration monitoring system; and
- a mode diagnostic system.

It is recommended that manipulators be used for all areas of inspection.

Comment (IRR)

The proposed measures will improve the assessment conditions of several materials in use. However, the main problem in applying advanced methods and instruments will be the partly restricted accessibility of specific areas, e.g. some vessel welds, vessel head, vessel head penetrations, piping welds, steam generator shell welds, and specific piping nozzles. To help overcome this situation, cost-effective tools have to be adopted for specific areas. Additionally, several compromises will have to be found in reliably determining a comprehensive catalogue of material properties and conditions. The success in this area will be strongly influenced by the amount of available funding.

Additional problems concern the persistent lack of qualification requirements for methods, personnel and equipment.

3.4.3 Issue: Steam Generator Collector Integrity

Horizontal steam generators are in use in all WWERs (see Figure 6).

Operational experience with WWER-1000s has revealed a number of problems with the steam generators' collectors and tubes; these are caused by improper design, manufacturing technology and adverse operating conditions. According to the information available, 28 steam generators have been replaced to date. Measures were proposed to overcome these conditions.

Planned Measures (Ukrainian Modernization Programme)

The measures proposed include:

- modification of the feedwater distribution inside the SGs;
- installation of a permanent blowdown line at the maximum saltification points;
- installation of a throttle-regulating device on the permanent and periodical blowdown lines;
- segregation of the permanent and periodical blowdown headers; and
- replacement of the blowdown water return lines from special water treatment with a 150 mm diameter pipe.
- redesign of a SG water level measuring system.
- development of an operational diagnostics system; and
- development of methods of processing the diagnostic information.
- development of devices for automatic monitoring of the volumetric activity of live steam and blowdown water.
- development of a noise diagnostic system for SG headers and other equipment.
- organizational and technical means to manage an accident involving primary to secondary leakage up to an equivalent diameter of 100 mm.
- accident analysis of a primary to secondary leakage caused by tube rupture or collector rupture.
- development of a computer-aided information system for the operational data of plant equipment.

The measures proposed *in terms of water chemistry improvement* include:

- implementation of the new temporary water chemistry standards with increased pH value in the primary circuit;
- determination of an optimum pH value with regard to the boric acid concentration change in a fuel cycle;
- improvement of the secondary circuit water chemistry control; and
- development and implementation of an on-line system for the automatic chemical monitoring of primary coolant parameters (pH, Xe, H_2).

Comment (IAEA)

The standard water chemistry regime is kept within the pH range 7.2 - 7.4. The hydrazine regime was tested at Zaporozhe.

No principal change for the primary and secondary regime is proposed. There are guidelines for primary and secondary water chemistry limits in case of departure from normal operating conditions.

Based on accident analysis results, the requirements for the leak detection system should be established.

All four SG collectors are checked by EC/NDE manually. One SG was checked using the Intercontrol manipulator to a limited extent. Due to the different techniques used, no comparison is possible .

A common database on chemical regimes, reliability and other items has been prepared by NTC Kiev for all Ukrainian NPPs. A specific database for items of the SG collectors has not yet been established.

Conclusions and Recommendations (IRR)

The safety issue has been addressed.

Regular NDE inspections on possible collector cracking should be performed with manipulators.

Comment (IRR)

Horizontal steam generators do have an advantage regarding natural circulation cooling in case of main coolant-pump failure. However, problems are also inherent to this type of steam generator. The proposed measures are likely to improve steam generator operation. Optimization of the operation can be achieved. Manufacturing problems and “environmentally assisted cracking” of the steam generator, however, will still remain a problem. For both units the condenser tube material is type Cu-Ni-Fe 5-1. No replacement is proposed in the Modernization Programme, which will not allow improvement of the secondary chemical mode.

However, recent experience with steam generators of WWER-1000/V-320 reactors calls for improving the chemical mode of operating the secondary side (IAEA/NEA IRS, 1997). Strong corrosion of the steam generator tubes was observed in the steam generators of the Balakovo 2 NPP.

Contrary to the IAEA assessment (IAEA-K2,1997) Atomaudit claims that hardware measures to eliminate safety relevant steam generator shortcomings have been developed (transition to corrosion-proof steel, reduction of the number of heat exchanger pipes in the most intense part of the collectors, perfection of manufacturing technology etc.) and are to a large part implemented in all working units (Atomaudit, 1997). However, it was not possible to verify this information on the basis of related documents.

Unless the above information is confirmed, the improper design of steam generators manufactured for R4 and K2 will probably not allow their operation until the end of the plant design life time.

3.4.4 Issue: Steam and Feedwater Piping Integrity

A failure of the highly energized steam lines is a generic problem for all power reactors. For WWER-1000/V-320 reactors the problem is complicated by the closeness of steam lines and feedwater pipes not separated by protective shields on the 28.8 m level between reactor building and machine hall. (See Figure 3)

The steam lines are endangered by the possibility of steam generator collector break and the resulting large primary to secondary leak (see Figure 6). This can lead to radioactive release and to a loss of primary coolant outside the containment. Therefore, greatest attention must be given to this serious safety issue.

Planned Measures (Ukrainian Modernization Programme)

The measure includes the development of rigid fixing of the steam pipelines and feedwater pipelines in the wall between the reactor compartment and the turbine hall.

The measure includes the LBB concept application to the primary and secondary circuits.

The measures proposed include:

- development and implementation of a system for pipeline dynamic fastening (SPDF) aimed at absorbing loads due to pipeline failure;
- development of the LBB concept for secondary circuit pipelines; and
- assessment of the dynamic effects of a primary to secondary leakage.

The measure proposed includes improving the secondary circuit water chemistry control.

Riskaudit additionally recommends the measure “Protection of Main Steam Isolation Valves and of Steam Dump Valves in Case of Rupture of Steam or Feedwater Lines” This measure should be implemented before start-up of K2 and R4.

Recommendation (Riskaudit)

Riskaudit has placed this issue under the topic: Multiple Failure of Main Steam and Feedwater Lines. According to their preliminary judgement, this issue potentially requires extraordinarily time-consuming and/or expensive measures and should be implemented before start-up of K2/R4.

Riskaudit additionally recommends the measure “Protection of Main Steam Isolation Valves and of Steam Dump Valves in Case of Rupture of Steam or Feedwater Lines”. This measure should also be implemented before start-up.

Conclusions and Recommendations (IAEA)

The safety issue has been addressed in the Modernization Programme.

The problem at the 28.8 m level is very complex. No simple solution for physical separation of the piping exists. One measure proposed is to mitigate the steam line and feedwater line break outside the 28.8 m level. Further assessments and measures are needed. The issue is recognized, but no complete solution exists.

It is recognized that the proposed modernization programme and the proposed measures indicate a determination to solve the problem.

Based on walkdown observations, the present fixtures of the steam and feedwater pipes near the division wall with the turbine hall seem to be reasonably rigid.

Comment (IRR)

This issue is addressed in the Ukrainian Modernization Programme (Kiev Institute et al., 1996). A satisfactory technical solution, however, is still pending.

Failure of the highly energized and not separated steam lines on the 28.8m level between reactor building and machine hall represents a generic problem of the WWER-1000/V-320 reactors. An extreme high vulnerability exists in this area for safety-relevant pipes, e.g. of the feedwater lines to the steam generators. This problem apparently cannot be fully solved by secondary measures like rigid embedding and separating walls. Primary measures are mandatory, e.g. rerouting and separating steam lines in combination with solid protection against pipe whip in case of failure. These primary measures are very cost intensive because they require a complete redesign of an area with limited space for improved installations. This may explain why such primary measures have not yet been taken in NPPs with

WWER-1000/V-320 reactors.

The IAEA experts' statement that "*the measures proposed indicate a determination to solve the problem"* does not really address the safety issue in a thorough and satisfactory manner.

3.5 Area: Systems

In case of a loss of coolant accident, coolability of ECCS heat exchangers can be impaired due to blocking caused by fibers from insulation. Effective coolability of the reactor core might therefore be impaired. Thus, special attention must be given to the related safety issue.

3.5.1 Issue: ECCS Sump Screen Blocking

Planned Measures (Ukrainian Modernization Programme)

The measures proposed include:

- an analysis of thermal insulation material (mineral filaments) behavior under LOCA conditions;
- an analysis of containment sump filters modification; and
- implementation of a final technical decision.

Comment (Riskaudit)

According to a preliminary judgement by Riskaudit, this issue potentially requires extraordinarily time-consuming and/or expensive measures and should be implemented before start-up of K2 and R4.

This issue is partly addressed in the Ukrainian Modernization Programme (Kiev Institute et al., 1996).

Comment (IRR)

Many imponderabilities are connected with this problem of sump screen blocking. They concern for instance the unknown height and direction of resulting primary forces that can be expected in the event of a LOCA. They relate also to the secondary forces resulting for example from jet impingement on walls, etc.

Thus, related on-site experiments or tests are generally poorly suited to verifying the effectivity of recommended, planned and taken measures. Their answers must be rated as limited.

One of the best and most cost-effective solutions appears to be the use of an insulation which is effectively protected against impinging jets resulting from possible leaks. Fiber-less insulation should be recommended to help overcome the problem. Also, a reliable fixing technology for the insulation has to be selected; it must be able to withstand any adverse environmental condition in the endangered area inside the containment.

3.5.2 Issue: Steam Generator Safety and Relief Valves

The qualification problem of safety and relief valves is not only a problem on the primary side (on the pressurizer) but also on the secondary side. This problem is also well known in Western NPPs. Safety and relief valves were generally designed for steam but not for two-phase mixtures and/or saturated water discharge.

Planned Measures (Ukrainian Modernization Programme)

Qualification for water flow of steam generator safety and relief valves.

The modernization programme includes a measure concerning the development of organizational and technical means to manage a primary to secondary leakage accident up to an equivalent diameter of 100 mm.

Furthermore, a replacement of the safety valves is planned.

Conclusions and Recommendations (IAEA)

The safety issue has been partly addressed.

The following measures are supported:

- installation of an isolation valve upstream of the safety relief valve (BRU-A). This valve will have to be qualified to close during water flow, so that a complete steam generator isolation can be ensured.
- studies of design and beyond design basis accidents and development of corresponding accident procedures. Results of studies can lead to additional qualification or demonstration being required for the steam lines, their isolation devices, and for steam generator safety and relief valves.

Comment (IRR)

Replacement of safety and relief valves is mandatory for the primary and secondary side in order to manage the possible fluid phases from steam to water under all emergency and accident conditions. They represent safety components that must operate reliably under every conceivable condition.

Based on Western experience, verifying the capability of such valves in test facilities is problematic because real boundary conditions cannot be recreated (e.g. boron environment in the case of primary side valves).

Nonetheless, efforts must be made to attain realistic and consistent boundary conditions for testing. Furthermore, reliable analytical verification of valve function under all possible flow conditions must be requested and performed.

3.6 Area: Instrumentation & Control

3.6.1 Issue: Reactor Vessel Head Leak Monitoring System

Lack of periodical testing of the leak detection system in the reactor vessel head can lead to non-detection of leaks in this area. Routine inspection is not possible on the outside surface. It is inaccessible due to the mounted steel coverage. Measures must be taken to overcome this situation.

Planned Measures (Ukrainian Modernization Programme)

The measure proposed includes a primary circuit leakage detection system.

Conclusions and Recommendations (IAEA)

The safety issue has been addressed and the discussions show that the intent of the recommendations will be met.

It should be noted that undetected leaks could lead to severe corrosion of the vessel head from the outside. It is recommended that experiences from the other WWER-1000/V-320 NPPs be monitored and their applicability to the K2/R4 be evaluated.

Comment (IRR)

Concerning the issue Reactor Vessel Head Leak Monitoring System and according to IAEA, *“the intent of the recommendations will be met*”. The proposed installation of a reactor vessel head leak monitoring system likely would resolve the issue.

3.7 Area: Electrical Power

3.7.1 Issue: Emergency Battery Discharge Time

In the event of a station blackout, the batteries are the ultimate DC energy source in the NPP for safety relevant equipment. A high reliability and an adequate capacity of these batteries are mandatory for monitoring essential plant parameters and controlling the safety significant motor-operated valves. In addition the batteries should be seismically protected.

Planned Measures (Ukrainian Modernization Programme)

The measures proposed include:

- analysis of the emergency DC power system in order to determine the modifications to be made to obtain 60 minutes discharge time in case of loss of off-site power supply (according to the IAEA Safety Guide N 50-SG-D7);
- replacement of batteries with those having a higher capacity, if the discharge time is less than 60 minutes before commissioning; and
- installation of automatic battery circuit monitoring equipment.

Conclusions and Recommendations (IAEA)

The proposed measures address the safety issue.

It is recommended that the reliability of the off-site power supply, the reliability of the emergency DC power system, and the emergency power consumption balance be reanalyzed taking the modernization of the emergency DC power system into consideration. The equipment’s capability to withstand earthquakes has been considered.

Comment (IRR)

The above issue can be resolved by the recommended measures.

3.7.2 Issue: Residual Life Time of Cables

According to a preliminary judgement by Riskaudit, this issue potentially requires extraordinarily time-consuming and/or expensive measures and should be implemented after start-up of K2 and R4.

Measure (Riskaudit)

Development of procedures and hardware to assess residual life time of cables.

Comment (IRR)

This issue is not addressed in the Ukrainian Modernization Programme (Kiev Institute et al., 1996). However, it is well known that aging of cabling represents a critical safety related issue especially for eastern type reactors. In the case of R4 and K2 this problem is complicated by the accelerated corrosion of cables due to the environmental conditions during the construction halt.

Power cable degradation, for example, can initiate a fire in a cable corridor. Many other scenarios can also result in common cause failures of safety-related equipment and components.

Thus, the present study strongly recommends investigating the aging situation of all currently installed cables in order to determine the necessity for replacement.

3.8 Area: Containment

The WWER-1000 containment structure (see Figure 2 and 3) includes walls which are 1.2 m thick, a dome which is 1.0 meter thick, and a base which is 2.4 m thick. The base of the containment section is located about 13 m above grade. The foundation slab is 3.0 m thick. The containment liner is made by welded plates of stainless steel and is 0.8 cm thick. The design pressure of the WWER-1000 containment is 0.41 MPa above the surrounding pressure. The free volume of the containment is about 70,000 cubic meters (See Figure 1).

The rooms between the base of the containment and the foundation slab are not part of the containment volume. They are used to install equipment for different systems, for example equipment for the main and emergency control room, etc. There is no steel liner in compartments used for ECCS and containment spray systems (whose piping is part of the primary circuit in case of LOCA); such a liner exists in the containment to provide leak-tightness under pressure loading.

Comment (IRR)

At this point, the situation described above appears to represent a potential generic severe accident vulnerability for the WWER-1000. If the situation described above is an accurate interpretation of the DOE report (DOE, 1987), it would appear that any severe accident which results in penetration of the bottom of the containment would result in a potentially large release of radioactivity into the environment. Even if the delay time required for this failure mode permits evacuation of the surrounding population, land contamination would still represent a severe consequence of the accident.

Finally, it is worth noting that the control room is located in a compartment beneath the containment. The control room could be uninhabitable in the event of a severe accident in which the bottom of the containment is penetrated by the core debris.

3.8.1 Issue: Containment Bypass

A number of scenarios lead to a bypass of WWER-1000 containment: rupture of steam-generator tube or collector; rupture of the MCPs' cooling circuit heat exchanger and subsequent breach in the intermediate cooling system outside the containment; failed isolation of the lines connected to the primary circuit and going through the containment in case of LOCA, etc. These would result in direct releases of radioactivity from the primary circuit and would jeopardize residual heat removal over the long term.

Recommendations (IAEA)

1. Study the necessity of installing membranes on the intermediate closed circuit inside the containment, both upstream and downstream of the heat exchanger, to ensure that a possible rupture takes place inside the containment. This would allow the collection of leaks in the containment sumps. The same modification could be envisaged upstream and downstream of the letdown after-cooler.

2. Within the framework of a review of the safety analysis report (TOB), attention should be paid to the LOCA transients which could bypass the containment. All the lines going through the containment should be checked and the possibility of isolating them from the primary circuit to avoid bypass of the containment should be analyzed (IAEA, 1993).

Planned Measures (Ukrainian Modernization Programme)

The measures proposed in the modernization programme include:

- installation of membranes on the pipes before and after the heat exchanger of main circulating pump autonomous circuit and letdown after-cooler;
- preparation of a complete list of accident analysis including containment bypass;
- upgrading of the leaktightness diagnostic system for ECCS heat exchangers; and
- development of NDT methods which are able to timely detect the defects developed on the ECCS suction line.

Conclusions and Recommendations (IAEA)

The safety issue has been addressed and the intent of the first recommendation has been met.

Regarding the second recommendation, no measure has been included in the programme. It is recommended that assessments of LOCA transients which could bypass the containment be specifically included either in the future SAR or in the Ukrainian modernization programme.

Comment (IRR)

This issue is addressed in the Ukrainian Modernization Programme (Kiev Institute et al., 1996).

Several possibilities for bypassing the containment barrier in the case of LOCA exist, e. g. via heat exchangers of the ECCS, or via steam generator collector failure to the secondary side, or steam generator tube rupture. The different paths must be thoroughly assessed by analytical methods and measures have to be developed to avoid containment bypass.

Although this issue is low ranked (I and II) by IAEA experts, it is listed in this context due to its importance for the defense in-depth concept . This is clearly demonstrated by the Balakovo 2 event (see chapter 3.4.3), which resulted in several thousand corroded steam generator tubes.

3.8.2 Issue: Containment Structure

The containment structure represents the last barrier in the defense in depth concept for an NPP. It is well known that Western experts argued after the Chernobyl accident that such a distribution of radioactivity over thousands of kilometers would never have occurred for an unit with a containment, which was obligatory for Western PWRs from the onset.

Comment (IRR)

From this point of view it is astounding that the IAEA and Riskaudit do not address the problem of tension losses in the prestressing cables of the containment (see Riskaudit, 1997). Only Riskaudit mentions in their report on R2/K4 (Riskaudit, 1996) that the strength of the containment has to be assessed. They also state that this can be performed after putting the plant into operation.

The IRR wishes to stress that any deficiencies of the containment have to be thoroughly investigated and assessed. Recommendations must be formulated. The necessary measures have to be fixed to overcome the tension losses in prestressing cables of the containment. Finally, these measures have to be taken *before* making the reactor critical.

Provisions should be made to reduce the leak rate of the WWER-1000 containment structure under pressure conditions. According to the original Russian design it is not more than 0.3% of the free volume per day, while for the updated Western PWRs' containment it is not more than 0.1% of the free volume per day. (Quantification of the effect of different leak rates on radioactivity release and radiological consequences under normal and accident conditions would need separate investigation.)

3.9 Area: Internal Hazards

3.9.1 Issue: Fire Prevention

Fire prevention in an NPP is one of the primary objectives. Nevertheless, measures must be taken to sufficiently protect safety-related equipment and components, e.g. cables against common mode failures due to fire.

Planned Measures (Ukrainian Modernization Programme)

The following measures are proposed in the modernization programme:

- replacement of combustible lubricating oil by non-combustible lubricating fluids;
- replacement of existing switching device of RTZO type for the prevention of a possible fire;
- overlapping of the cables with fire-resistant coating;
- replacement of existing fire doors;
- monitoring of the cooling of the MCP motor;
- improvement of fire resistance of the turbine hall steel structure; and
- development and implementation of measures for automatically dumping hydrogen from the generator housing to outside the turbine hall in case of a fire hazard.

Conclusions and Recommendations (IAEA)

The safety issue has been addressed. The measures proposed and the discussions indicate that the intent of the recommendations will be met.

Comment (IRR)

As reported by the IAEA, a dangerous fire takes place in an NPP every 10 years. The primary task is to avoid any fire hazard in an NPP, i.e. to prevent fires from starting. Nevertheless, fire detection, protection and fire-fighting systems must be installed to detect, fight and limit fire to specific areas. These areas have to be composed in such a way that no fire expansion is possible. The possibilities of fires and their effects on safety require a much more detailed treatment than performed by the IAEA experts. A minimum requirement would be a PSA, allowing to quantify the effective increase in safety due to specific measures.

3.9.2 Issue: Pipeline Breaks Impact Inside the Reactor Building

According to a preliminary judgement by Riskaudit, this issue potentially requires extraordinarily time-consuming and/or expensive measures and should be implemented before start-up of K2 and R4.

Measure (Riskaudit)

Carry out special analysis to determine the extent of pipeline breaks impact inside the reactor building.

Comment (IRR)

This issue is addressed in the Ukrainian Modernization Programme (Kiev Institute et al., 1996). Special attention has to be given to the impact of pipe breaks inside the reactor building on safety-related components and equipment. The results of corresponding analysis have to be followed by appropriate hardware measures.

3.9.3 Issue: High Energy Pipes Ruptures

According to a preliminary judgement by Riskaudit, this issue potentially requires extraordinarily time-consuming and/or expensive measures and should be implemented before start-up of K2 and R4.

Measure (Riskaudit)

Elaboration of a special methodology to identify hazards related to high energy pipes ruptures and to perform a complete analysis of the units.

Comment (IRR)

This issue is only partly and insufficiently addressed in the Ukrainian Modernization Programme (Kiev Institute et al., 1996). Additional analytical efforts are necessary to determine the reasons for and consequences of high energy pipe ruptures. These considerations should give rise to several hardware measures. The possibility of implementing such measures must be investigated.

3.10 Area: External Hazards

3.10.1 Issue: Extreme Weather Conditions: Low Temperature

According to a preliminary judgement by Riskaudit, this issue potentially requires extraordinarily time-consuming and/or expensive measures and should be implemented before or after start-up of K2 and R4.

Measure (Riskaudit)

Perform demonstration that NPP can cope with any accident situation when the temperature is low.

This demonstration should be performed: firstly, when the temperature does not exceed the "average minimal temperature", secondly, under an extreme cold condition.

Comment (IRR)

This issue is partly addressed in the Ukrainian Modernization Programme (Kiev Institute et al., 1996). It might gain significant safety relevance, e.g. for emergency cooling water tanks. The related heating system must be able to cope with all low temperature situations.

3.10.2 Issue: Man-induced External Hazards and Seismicity

The high accumulation of radioactive material in the NPPs represents a great danger potential. Man-induced external hazards on the NPP, e.g. potential military and terroristic attacks, must be considered in order to develop measures to prevent and mitigate even such scenarios.

Comment (IRR)

This issue must be included into a site-specific modernization programme. It is not yet formulated in any of the available documents.

3.11 Area: Accident Analysis

3.11.1 Issue: PSA

Under Western practice, nuclear plants are not permitted to operate until a comprehensive Probabilistic Safety Analysis (PSA) has been prepared, reviewed and approved. According to the IAEA recommendations, PSA, at least level 1 including internal and external events and hazards, should be performed for all WWER-1000 units. *"The target for existing nuclear power plants consistent with the technical safety objective is a likelihood of occurrence of severe core damage that is below about 10^{-4} events per plant operating year. Implementation of all safety principles at future plants should lead to the achievement of an improved goal of not more than about 10^{-5} such events per plant operating year. Severe accident management and mitigation measures should reduce by a factor of at least ten the probability of large off-site releases requiring short term off-site response."* (INSAG-3, 1988)

Until now, PSA results for WWER-1000 units have been obtained only for Balakovo 4, Kozloduy 5&6 and for Temelin 1. The PSA Level 1 study for Balakovo 4 includes a limited number of internal initiating events and the results are too optimistic.

For Kozloduy 5&6, after carrying out a number of safety improvements during 1992-95, the reported CDF from the level 1 PSA is 3.7 E-4 per year (late 1996). Not all external initiating events are included, but it is known that they could substantially contribute to the final CDF - about 50 % and more. Human behavior is not evaluated either and only full power conditions are covered.

For the Temelin NPP the level 1 PSA (for internal initiating events only, the shutdown mode is included) yielded a core damage frequency of 0.76 E-4 per year. It can be concluded that modernization measures for WWER-1000 units have a generically limited scope and that the results even for the Temelin NPP are not overly optimistic (Lederman, 1996; MHB, 1989).

The expected PSA results for the Ukrainian NPPs discussed above will no doubt be much worse. In the Ukraine, three PSA projects are in various stages of development.

For Rovno NPP unit 1 and 2 (WWER-440/V-213), the PSA is provided with the technical and financial support of the U.S. NRC and has been completed to nearly 50%. For South Ukraine NPP unit 1 (WWER-1000 / V-302), a PSA was started in 1996 and is far from completion. The above two projects are performed by Ukrainian institutions.

The third project, for the Zaporozhe NPP unit 5 (WWER-1000/V320), was contracted to the Russian designer. Lack of funding has resulted in little progress being made on this project. No plans exist for conducting plant-specific PSAs for Khmelnitsky 2 and Rovno 4 (IAEA-R4, 1995; IAEA, 1996, Kopchinsky et al., 1996); Safety Analysis Reports satisfy the Ukrainian legal requirements (Atomaudit, 1997).

Due to the delay necessary to perform the probabilistic study of a total station blackout, for example, the compensatory measures should be defined as soon as the weak points have been identified. The following points require investigation: - means to maintain primary circuit integrity; - means to inject borated water; - means to continue decay heat removal by the secondary side; and - means to recover electrical power for needed equipment (IAEA-R4, 1995; IAEA, 1996).

To date, no definitive list of initiating events for accidents under low power and shutdown (LPS) conditions exists. The preliminary list mainly includes events linked to a dropping of the container onto the pool and fuel assemblies. The rules applicable to the performance of such studies are presently not available. There is also no detailed information on rules applicable to a backfitting decision. It has been understood that PSA results would be one element of the decision-making process.

Comment (IRR)

Plant-specific PSAs have not been performed for K2 and R4. The proposed modernization programme is not based on probabilistic results and criteria, but merely on practical experience and deterministic assumptions. Nevertheless, it is also stated that probabilistic criteria will be used for decision making.

Without performing a plant-specific PSA the, contribution of a measure to overall NPP safety cannot be evaluated. However, PSAs can provide figures to indicate the relative safety improvement.

3.11.2 Issue: Rapid Reactivity Increase

The rapid reactivity and power increase in WWER-1000s during operation could be caused mainly by control rod ejection. Sixty-one neutron absorbers (control rods), can be moved up and down in the core by individual drive mechanisms. The WWER-1000 control rod drive mechanisms are installed in the housings, which are connected to the reactor upper unit and thus to the primary circuit. In the case of sudden rupture of the particular housing, large pressure differences will eject the corresponding control rod and the drive shaft to the fully withdrawn position within 0.1 - 0.2 s. In the event that the control rod was initially inserted in the core, the consequences of this failure are rapid increase of the neutron flux and thermal power, with an adverse power distribution in the core.

The effect depends mainly on which of the 61 control rods will be ejected, its initial position, and the initial neutron flux distribution. The transient could be mitigated by the negative reactivity feedback and terminated by actuation of the scram system. However, in some cases (effective control rod fully inserted in the core) the rapid control rod ejection could result in fuel melting, damage to the fuel rod cladding, and damage to the primary circuit boundary. After such an accident, the possibilities to cool the core could be significantly affected. Sudden rupture of a control rod drive mechanism housing will also perforate the reactor upper unit, leading to loss of coolant accident.

The consequences of such an accident are restricted by the limited reactivity efficiency of a single neutron absorber and by the presence of control rod insertion limits, which vary as a function of power level. However, the control rod insertion limits for WWER-1000s are assured not by technical means, but merely by administrative measures. The reactor operator is fully responsible for remaining within these limits and they could be easily violated during some transients. The reactor is operated with control rod group No. 10 partially inserted in the core and, as a rule, well above the insertion limits; nevertheless it could be also operated with control rods near or below the insertion limits after unplanned changes of the power level. In the beginning of fuel cycles, or after scrams, the reactor could be operated by control rod group No. 9, while group No 10 is fully inserted.

Comment (IRR)

According to the original Russian design, during physical start-up of WWER-1000s the control rod groups Nos. 10 and 9 are fully inserted in the core in order to decrease the boric acid concentration in the primary coolant and to obtain a negative temperature reactivity coefficient. The criticality and power level of the core are controlled by group No. 8.

According to the Modernization Programme, no plans exist to use fuel of new design, burnable neutron absorbers, or new patterns for the initial fuel loading of K2/R4. Finally, the process of commissioning these units will follow the traditional approach along with the above-mentioned safety deficiencies.

A complete set of rod ejection analyses must be accomplished for the start-up phase of operation of K2 and R4, taking into consideration the potential severity of this type of accident.

3.12 Area: Spent Fuel and Radioactive Waste

3.12.1 Issue: Spent Fuel Storage

For K2 and K4 WWERs-1000 the initial enrichment of the fuel is 4.4 %. Each assembly has a total weight of 716 kg and contains 430 kg U. According to the design its life-time is three cycles and the fuel reaches an average burn-up about 40 MWdays per kg initial U. Annually about 55 fuel assemblies, containing a total of 23.6 t of heavy metal, are reloaded from each WWER-1000, which use nuclear fuel for 3 cycles. This is equivalent to about 605 assemblies per year from all 11 operating nuclear units of this type in Ukraine.

The irradiated nuclear fuel contains about 200 radioactive isotopes with a different period of life-time. By the time of off-loading of spent nuclear fuel from the reactor core its radioactivity is about 1000 Ci per kg and the residual heat, caused by it, is about tens of W per kg. A considerable amount of Pu is generated in the spent nuclear fuel, which is about 6-7 kg per t initial U for the above-mentioned burn-up. These factors require cooling of the spent nuclear fuel in water ponds during first years.

In the previous system for nuclear cooperation in the former USSR, spent fuel from Ukrainian WWERs-1000 was managed in the following way: After 3-4 years storage in plant’s cooling pools, irradiated assemblies were transported for intermediate storage at the industrial complex in the Krasnoyarsk region. At the present time this storage facility is nearly full. Due to lack of funds, the radiochemical part of the complex is far from completion. It is estimated that by the year 2000 the situation will become critical and the Krasnoyarsk plant will be forced to stop receiving spent fuel assemblies.

After 1992 the new Russian ecological law came into force and the shipment and storage of Ukrainian spent nuclear fuel on the territory of Russia was blocked. An agreement between the governments of Ukraine and Russia was subsequently signed and in 1995 the shipment of Ukrainian WWER-1000 spent fuel to Krasnoyarsk plant was reactivated. Because of the unstable political relations between the two countries, however, this solution is unreliable. Some initiatives were undertaken by NPPs to find temporary solutions for intermediate storage of the spent fuel in dry concrete containers, using American technology. It must be stressed that no other solution to the problem of spent fuel storage from WWER-1000 reactors currently exists in Ukraine.

Comment (IRR)

This area is not included in the Ukrainian Modernization Programme. The back-end of the Ukrainian nuclear fuel cycle remains indefinite. The possible options - intermediate storage, spent fuel reprocessing and/or final storage of high radioactive waste - are decades away from a final decision.

The K2/R4 spent fuel ponds can be up-dated in accordance with the practice in other plants. The total number of positions in each spent fuel pond can be increased to about 610. Finally, it is possible to store the spent fuel from five refuelings plus the fuel from reloading of the full reactor core under emergency conditions. This is a short-term decision, but no other solution to the problem of spent fuel storage from the K2/R4 reactors currently exists in Ukraine.

3.12.2 Issue: Radioactive Waste Management

The situation with regard to the reprocessing and storage of existing radioactive waste is also critical. "*Ukrainian nuclear power plants alone have already amassed more than 60-million cubic meters of waste, and another 50-million cubic meters have been produced by the uranium industry*" (NW, 1995b). Ukrainian plants were designed mainly in the 1970s, when radwaste policy was not yet established and technologies for radwaste treatment, compacting and disposal were not approved. The Law of Ukraine on Radioactive Waste Management was put into force in June 1995.

Due to the lack of regional or centralized waste storages, all liquid and solid wastes are stored at NPP sites. Two special buildings with solid waste treatment module and storage facilities exist for WWER-1000 reactors. Pilot-type minimization technologies and treatment facilities have only been introduced over the last few years. As a common practice, liquid waste is mixed and stored in reservoirs without separation dependent on the activity level or on the radionuclide and chemical content. Because a proper infrastructure for waste treatment and management was lacking in Ukraine, all technologies and facilities used were manufactured in Russia.

Comment (IRR)

This issue is not included in the Ukrainian Modernization Programme. Rovno NPP has a bituminization facility, which was commissioned over the last three years despite the lack of liquid waste storage reservoirs. The waste management strategy of the plant remains to be formulated. At the Khmelnitsky NPP a high concentrate evaporation facility is in operation, and work for designing a radwaste treatment complex (NUKEM technology) is under way.

Due to the lack of national waste repositories, the practice of using sites at Rovno and Khmelnitsky NPP for waste storage (for an indefinite period) will continue. This approach - using the benefits of nuclear power now and shifting all unresolved problems to the next generations - must be terminated.

4 Additional Safety-Related Aspects

4.1 Post Three Mile Island Requirements

These requirements comprise a list of 35 items which resulted from the lesson of the accident in Three Mile Island (TMI) NPP in 1979. The TMI accident was one of the largest accidents in Western NPPs and initiated a set of important safety improvements for all NPPs. The accident had a strong impact on areas such as safety analyses, management practices, safety systems and safety culture, improvements of calculational codes, personnel training, investigation of severe accidents, extension of design base accidents, etc.

Comment (IRR)

The “Post TMI requirements” (NUREG 0737, R.G. 1.97) are of special safety relevance. They are addressed to some extent in the Modernization Programme for Ukrainian Nuclear Power Plants (Kiev Institute et al., 1996) without addressing them as “Post TMI requirements” . An overview of the situation of having taken into account the requirements is given in the following table.

The table comprises 35 requirement items, 8 are fully and 3 are partly (i.e. not completely related to the original content of the requirement) addressed in the Ukrainian Modernization Programme. The important technical items, however, are addressed in the Ukrainian modernization programme. They are generally ranked as class II issues in the IAEA Issue Book for the WWER-1000/V-320 reactors (IAEA, 1996). Logistic items are generally not explicitly addressed in the Ukrainian modernization programme.

Recommendation (IRR)

It is highly recommended that the as yet unaddressed TMI requirements be included in the modernization programme for K2/R4.

NUREG 0737	**ITEM**	Addressed in Ukrainian Modernization Programme
I.A.1.1	Shift technical advisor	yes, explicitly mentioned
I.A.1.2	Shift supervisor responsibilities	not explicitly mentioned
I.A.1.3	Shift manning	not explicitly mentioned
I.A.2.1	Immediate upgrading of RO & SRO training and qualification	not explicitly mentioned
I.A.2.3	Administration of training programs	Yes, explicitly mentioned
I.A.3.1	Revise scope and criteria for licensing exams	not explicitly mentioned
I.C.1	Short-term accident and procedure reviews	not explicitly mentioned
I.C.2	Shift & relief turnover procedures	not explicitly mentioned
I.C.3	Shift supervisor responsibility	not explicitly mentioned
I.C.4	Control room access	partly
I.C.5	Feedback of operating experience	Yes, explicitly mentioned
I.C.6	Verify correct performance of oper. activities	not explicitly mentioned
I.D.1	Control room design reviews	Yes, explicitly mentioned
I.D.2	Plant-safety-parameter display console	partly
II.B.1	Reactor coolant system vents	not explicitly mentioned

II.B.2	Plant shielding	not explicitly mentioned
II.B.3	Post accident sampling	Yes, explicitly mentioned
II.B.4	Training for mitigating core damage	not explicitly mentioned
II.D.1	Relief & safety valve test requirements	Yes, explicitly mentioned
II.D.3	Valve position indication	not
II.E.1.1	Auxiliary feedwater system evaluation	not
II.E.1.2	AFW system initiation & flow	not
II.E.3.1	Emergency power for pressurizer heaters	not
II.E.4.1	Dedicated hydrogen penetrations	not
II.E.4.2	Containment isolation dependability	not
II.F.1	Accident-monitoring:	
	Noble gas monitor	not
	Post accident sampling	Yes, explicitly mentioned
	Containment high range radiation monitors	Yes, explicitly mentioned
	Containment high range pressure monitor	Yes, explicitly mentioned
	Containment high range H_2 concentration	Yes, explicitly mentioned
II.F.2	Instrumentation for detection of inadequate core cooling	Yes, explicitly mentioned
II.G.1	Power supplies for press. relief valves, block valves and level indicators	Yes, explicitly mentioned
II.K.1	IE Bulletins	not
II.K.3	Final recommendation B&O task force	not
III.A.1.1	Emergency preparedness short term	not explicitly mentioned

III.A.1.2	Upgrade emergency support facilities but TSC and OSC	not explicitly mentioned
III.D.1.1	Primary coolant outside containment	not
III.D.3.3	Improved In-Plant Iodine Instrumentation Under Accident Conditions	not explicitly mentioned
III.D.3.4	Control Room Habitability Requirements	partly

4.2 Vintage Design of K2 and R4 - Rules, Norms and Standards

Zaporozhe 1 (Z1), which was designed in 1978, was the reference plant design for all Ukrainian WWER-1000/V-320s. The design of Z1 took into account the norms, standards and rules in force in the USSR at that time. (For example: General Provisions for NPP Safety Assurance Under Designing, Erection and Operation 0PB-73, 1973). The design of the other operating WWER-1000/V-320 reactors (Zaporozhe 2-5, South Ukraine 3-4, Khmelnitsky 1 and Rovno 3) was developed on the Z1 design with some amendments resulting from safety and reliability improvements. (Kiev Institute et al., 1996). According to the project management of the Ukrainian Modernization Programme (Kiev Institute et al., 1996), additional amendments have been included in the construction of Z6, K2 and R4.

Concerning the original design of K2 the IAEA stated "*The unit has a design elaborated in accordance with general rule OPB-73 and norms/standards being in force at that time. The design of the plant does not entirely comply with the current safety standards, and the GOSKOMATOM and Khmelnitsky NPP decided to introduce the modernization programme to upgrade the plant*." (IAEA-K2,1997)

The same was stated for R4 (IAEA-R4, 1995).

In April 1993 an IAEA report (IAEA, 1993) identified 16 areas in which the WWER-1000 design standards and codes are deficient when compared to U.S. regulations and IAEA standards. These include:

- Severe Accidents;
- Common Mode Failure;
- Missile Protection;
- Fire Protection;
- Classification of Components;
- Reactor Core Design;
- Core Power Distribution and Xenon Oscillations;
- Heat Transfer to an Ultimate Heat Sink;
- Radiation-Induced Embrittlement of Pressure Vessel Steels;
- Containment Design Basis;
- Hydrogen Control;
- Instrumentation and Control;
- Overpressure Protection;
- Safety Analysis Report;
- Quality Assurance Program;
- Component Failures and Human Errors Data.

Comment (IRR)

The basic safety principles of WWER-1000s are similar to those of the Western PWRs of the early 1970s. However, their original design does not appear to be organic and is too complicated; it resembles a conglomerate of a number of systems outfitted with rather old and poor-quality equipment requiring considerable protection and control automation. There are several reasons for the relatively low safety level and poor performance indicators of the plants. These include the obvious limited and simple specific considerations about NPP safety, the absence of quality assurance programs, and the lack of safety culture in all organizations involved in the design and construction of operational units.

Soviet Rules, Norms and Standards

The general rule OPB-73 was set up in the early 1970s in the former Soviet Union. At this time, safety assessments of WWERs were not performed in accordance with international approaches.

The spectrum of accident analyses was relatively limited. The computer codes and the computers used were of poor quality. The need for systematic training of operational and maintenance personnel was underestimated. Full-scope simulator training for reactor operators was not provided. No testing was accomplished for the beyond-design accidents. In-depth analysis of common-cause failures and external hazards for safety systems was incomplete. The equipment for WWERs was often of unsatisfactory quality, without needed tests and data for its reliability. No provisions were made for age-related deterioration of the equipment. The practice of accomplishing the Probabilistic Safety Assessment even for the reference plants was unknown. There were no independent companies for safety evaluations in the former Soviet Union.

The up-date Russian regulation OPB-88 was developed because of accidents such as Three Mile Island (TMI) in 1979 and Chernobyl in 1986 and the development of new safety methods such as PSA and operational experience feedback. The differences between OPB-73 and OPB-88 are (according to Kirmse et al., 1996) in the areas of:

- safety culture,
- quality assurance of safety relevant components and systems,
- consequent introduction of safety level 4 (Accident management including confinement protection.),
- use of PSA for safety evaluation.

Improved accident analysis became possible with western computer codes adapted to soviet design (Atomaudit, 1997).

Comment (IRR)

OPB-88 are the equivalent of the NUSS (Nuclear Safety Standards) of IAEA, which represent the internationally accepted western safety regulations in the sphere of nuclear power. According to IAEA *“The analysis of the Russian NPP safety concept contained in OPB-88 and the next lower level Norms/Rules and its comparison with the NUSS requirements shows that while the concepts are the same, there are differences with respect to approaches and details.”*

In this context it is important that compliance with OPB-88 and therefore Western safety standards will only be reached by the generation following WWER-1000/V-320 reactor types. The present WWER-1000/V-320 reactor type does not comply with OPB-88 in respect to important issues (see the following table).

Even in the upgraded form, K2 and R4 will not fulfill OPB-88 and therefore Western safety standards - in essential points.

The following table presents a historical overview of different WWER-1000 reactor types and their compliance with Russian regulations (Kirmse et al.,1996).

Table: Historical overview of different WWER-1000 reactor types and their compliance with Russian regulations (Kirmse et al.,1996):

Time	Reactor Safety Improvement	Compliance with Russian Regulations	WWER-1000 Type	
90ies	• core melting scenarios • passive safety systems • safety and aging • digital I&C		V-428 V-392/410	planned
80ies	• introduction of safety level 4 • plant internal emergency plans • operating experience feedback	OPB-88 OPB-82		
70ies	• systematic PSA • beyond design base accidents • extension of design base accidents • automatization	OPB-73	V-320 V-338 V-302 V-187	operating or under construction
60ies	• concept of different safety levels (3) • multi barrier concept • design base concept			

4.3 Safety Problems in Other WWER-1000/V-320 Upgrading Projects

The following two options are the bounds of a spectrum of possible options for completing WWER-1000/V-320s. On the one hand, Zaporozhe 6 was completed without Western funds and technical cooperation. On the other hand, the Temelin NPP is being upgraded with the intensive help of U.S. technology, equipment, and financing.

Both options are confronted with significant technical problems. Neither of the two approaches are satisfactory from the safety point of view, not to mention the economic aspect.

4.3.1 Zaporozhe 6

The most recent nuclear power reactor, Zaporozhe 6 (Z6), which is a WWER-1000/V-320 type reactor, started operation in November 1995.

Construction of Z6 began in 1986. Due to the Ukrainian moratorium within the period 1990-1993, the construction of Z6 was frozen at a level of 95% of completeness. Thereafter, Zaporozhe unit 6 was completed without Western funds and technical cooperation.

In October 1995, Zaporozhe 6 was granted a trial operation license, but it expired in 1996. Coincidentally, at exactly the same time, the reactor was shut down for refueling and maintenance. In 1997 the Ukrainian Nuclear Regulatory Authority (NRA) decided not to renew the operating license for Zaporozhe 6 due to still unresolved design problems

Comment (IRR)

Although the level of completeness of Z6 after the moratorium was much higher than for K2 and R4 and the infrastructure at the site, which is the largest NPP in Europe and consists of 6 units, is better than in Khmelnitsky (with only one operating unit), the operating situation is unsatisfactory.

4.3.2 Temelin NPP

The two Temelin reactors are built according to the Soviet WWER-1000/V-320 reactor design. Construction work started in 1982 for Temelin 1 and in 1985 for Temelin 2. In 1993, the Czech Government launched the decisive effort to complete construction of the Temelin Nuclear Power Plant - which was initiated by the former Communist regime - with the help of U.S. technology, equipment, and financing.

Important safety-related problems of the Temelin NPP

1. Change of main designer

This is unique in the world of NPP construction practice, namely the change of the Main Designer without any handover of critical functions or know-how transfer. Additionally, a number of changes to the design of the Temelin NPP were carried out by Czech organizations. They were not coordinated with the original Russian Design organizations and did not take advantage of operational experience. Thus, in the Temelin NPP project there is no clear separation of responsibilities between participating design organizations for the final safety of the resulting hybrid plant. This melding of Russian and Western technology, with their different standards and regulations, compounded by the very late design stage, represents an unprecedented risk.

2. Re-engineered reactor core

The Westinghouse re-engineered reactor core has not been tested under real WWER-1000 operating conditions and will undergo its first full tryout phase during the start-up phase of the Temelin NPP. This is in full contradiction to one of the main IAEA safety principles, which requires that only well-tested, proven technology and components be utilized in NPP construction; this poses high risk potentials to the environment.

3. I&C system

The successful implementation of the I&C system redesigned by Westinghouse for the Temelin NPP is questionable, taking into consideration the relatively limited operational experience gained in distributed digital I&C systems, as well as the increased number of sensors, cables and connections needed at the Temelin NPP. The lack of field tests and experience under operational conditions of WWER-1000s are additional problems.

4. Fuel assembly bending and control rod cluster jamming

One dangerous issue in WWER-1000 core design, namely fuel assembly bending and control rod cluster jamming, was not recognized in the West prior to 1994. High priority must be given to clarifying the basic reasons for the jamming. This proves once again that the project was and continues to be inadequately understood.

5. Water chemistry regimes

The different water chemistry regimes of the primary coolant in the Westinghouse versus Russian designs and the lack of long-term tests do not allow potential corrosion problems to be evaluated. Thus, the long-term fuel cladding integrity is not ensured.

6. Secondary systems integrity

Some of the major safety concerns have not been addressed to the extent required. The secondary systems integrity is heavily jeopardized by the physical arrangement of the high-energy piping and components, located on the 28.8 m elevation area in the intermediate building. Subsequent to an accident in this area, recriticality of the reactor core, for example, could lead to catastrophic consequences.

7. Quality Assurance

Quality Assurance programs have not been stepped up to the required size of effort. Civil engineering structures containing safety-relevant installations are of questionable quality. Low standards during the initial construction period have led to a very unfavorable situation concerning the quality of concrete, reinforcements, foundation stability, as well as of the containment structure as a whole. Affidability and reliability of the plant are, therefore, still questionable. QA is apparently considered to be a minor contribution to safety in the case of the Temelin NPP. This is in contradiction to international practice and represents a major safety concern.

8. Set of unique equipment and team of highly qualified experts from design organizations

From the operational experience with WWERs, it is well known that successful completion of the preoperational cold and hot tests of NSSS requires prerequisites which are not available for the Temelin NPP: a set of unique equipment, a team of highly qualified experts from design organizations, and computer codes to calculate test data and to evaluate equipment characteristics. This means an additional major effort for the Temelin NPP, i.e. considerable delay and cost overruns plus the risk of plant malfunction.

In light of all the above, there is considerable concern that U.S. and Czech companies lack the design, experimental, and operational information required to ensure the proper safety upgrading, start-up and operation of the resulting hybrid project. The consequences may well be detrimental to the plant and its owner during the period of start-up.

Spectrum of additional problems at Temelin:

- Calibrating in-core detectors
- Xenon oscillations and power density
- Inadequate data acquisition for PSA
- Storing radioactive waste, which is also an important cost factor.

Comment (IRR)

Important preconditions for the completion of Temelin NPP are met much better than for K2 and R4: The construction work at Temelin has been continuous and therefore mothballing and preservation were never a major issue at this site. The construction work at K2 and R4 is more advanced than at Temelin. Therefore the implementation of major design changes is more difficult and expensive. The industrial environment as well as the financial situation in the Ukraine is much worse than in the Czech Republic and therefore cannot be compared; in addition, there is an intensive input of U.S. technology, equipment and financing.

Nevertheless, the Temelin project management is confronted with significant technical problems. Due to the complexity and the unique nature of the hybrid East-West design, a wide range of problems in redesigning and installing Western I&C appeared. All of these problems remain unresolved despite almost three years of intensive effort.

"At the press conference on Friday, April 29th [1997], *CEZ representatives admitted that the most serious problems at Temelin are linked to the Westinghouse supplies. These include not only cable layout but also delays in software development (this software is a key part of Westinghouse's Instrumentation and Control System package). Vojtech Kotyza, Member of CEZ Board responsible for Temelin, also said at TV Nova main news on Sunday evening that Westinghouse seriously underestimated the scope of projects for Temelin upgrades. He reacted on the information published in Nucleonics Week. According to Kotyza, recent Westinghouse problems may result in further delays and additional cost overruns at the magnitude of 7bn CZK"* (CEZ, 1997).

These serious technical problems are reflected in time delays and cost overruns. The 1992-93 CEZ assessments of the time schedule and upgrading costs prove to be underestimated and unrealistic. Completing the Temelin NPP will clearly result in time delays in the range of 2.5 to 5 years and cost overruns of US$1bn or more compared with the original estimates.

5 Viability of the K2/R4 Modernization Programme

Any adequate evaluation of the safety relevant aspects of nuclear power technology requires going beyond mere technical considerations due to the mutual interdependencies of technical, logistic, infrastructural and economic factors. This interdisciplinary approach also dictates devoting some attention to the financial environment.

In their “Evaluation of the Modernization Programme” for K2 and R4, Riskaudit identified a number of issues which, according to their preliminary judgement, potentially require extraordinarily time-consuming and/or expensive measures (Riskaudit, 1996). Not all of these measures are finally considered in the Ukrainian Modernization Programme, revision 2 (see below).

Furthermore, site-specific measures which could also be very relevant for plant safety are not treated to a large extent (for example Inadequate Mothballing, see below) and will certainly contribute to the costs.

As mentioned in the Introduction (chapter 1.1), according to EBRD the completion costs for K2/R4 are in the order of US$1.2bn, and 30 months have been allotted for construction work prior to start-up.

However, in contrast to the above information, the Ukrainian Goskomatom and the Ukrainian Ministry of Energy mentioned, according to a joint report of the US DOE (DOE et al., 1994), 89 months and US$485mn for completion and upgrading of K2, and 74 months and US$495mn for completion and upgrading of R4. This time schedule appears more reasonable.

Temelin, also an NPP with WWER-1000/V-320 reactors, is located in the Czech Republic and is already on the way to being completed with Western support. Completion of the Temelin NPP will experience time delays in the range of 2.5 to 5 years and cost overruns of US$1bn or more compared with the original estimates.

“We have little confidence in any of the various elements of the estimated costs of completing and operating K2/R4, including waste disposal and decommissioning. This basic lack of confidence in the cost estimates makes K2/R4 a high risk investment - especially as we have no reason to think that the avoidable cost of generation from most of the existing fossil fuel plants would be higher than the generating cost of K2/R4 (including the investment cost and an appropriate return on capital)”. (Sussex, 1997)

Comment (IRR)

The uncertainties in estimating the time frame and costs for the Ukrainian Modernization Programme are cause for concern about the safe realization of K2/R4. One possible scenario might be that the international credits are only sufficient to complete the K2 and R4 reactors at a rather low safety standard, and that the lack of additional funding will prohibit the realization of important safety relevant upgrades. The result would be insufficient safety standards near the level of the internationally criticized, originally flawed design of the WWER-1000/V-320.

Proper cost and time frame estimations of the above-mentioned open or neglected issues are apparently not yet possible. Their influence on the feasibility of the Modernization Programme, especially on the issue of safety upgradings, is unknown.

6 Conclusions

Area: Logistics

Unfavorable *logistic* and *infrastructural* preconditions, including economic, political and societal aspects, significantly contributed to the root causes of the TMI and Chernobyl accidents. Such logistic and infrastructural issues have a considerable influence on nuclear safety and cannot be resolved by a set of relatively simple measures. In the Ukraine they impair the safety of all the nuclear power plants and would have a particularly negative effect on the completion and subsequent operation of K2/R4.

The poor overall *Economic Situation* demotivates current staff and future personnel and has strong repercussions on plant safety. It represents a major element in an unsatisfactory environment for nuclear power technology as a whole. Due to the lack of financial and industrial resources the supporting infrastructure is not favorable for the further development and growth of nuclear power in the Ukraine.

Since the disintegration of the USSR, the Ukrainian NPPs have been confronted with the loss of main parts of the formerly powerful *Nuclear Infrastructure*. In particular, the loss of the Soviet main designer organizations, architect engineer organizations and scientific institutions, which played a central role in completing and operating NPPs, has had a very negative effect on nuclear safety. The Ukrainian supporting infrastructure is not favorable for the further development of nuclear power.

The nuclear *Safety Culture* in Ukraine is still insufficiently developed. The overall negative situation is reflected for example in the unsatisfactory performance of the currently operating NPPs as well as the resignation of the vice-chairman and chairman of the Ukrainian Nuclear Regulatory Authority (NRA) in 1993 and 1994.

The still unresolved problems with the delivery of *Spare Parts* and *Replacement of Degraded Equipment*, as well as with the poor quality of the F*resh Nuclear Fue*l elements in operating NPPs, underline the Ukraine’s poor ability to meet even normal technological requirements.

Area: General

Preservation and Mothballing, essential preconditions for safe and reliable completion of K2/R4, were marginal or neglected altogether during the Ukrainian moratorium from 1990 to 1993. The resulting situation remains to be assessed. These issues are missing in the project time frame and cost estimations and both are thus underestimated. They also no doubt have a considerable negative impact on the quality of equipment, although this appears not to have been adequately considered. A thorough and complete programme for *Equipment Qualification* has significant cost and time implications.

Area: Core

Control Rod Insertion Reliability/Fuel Assembly Deformation is an as yet unresolved generic safety issue of WWER-1000/V-320s[12]. The root causes for failures in several plants remain to be identified. A variety of potentially very expensive and/or time-consuming measures is proposed, their final effectivity is uncertain.

The requirement for an automatic *Power Density Control System* and automatic equipment for *Xe-Oscillations* suppression is partly addressed in the Modernization Programme. This potentially very expensive and/or time-consuming measure is not the practice for Soviet-designed units operating in base load mode. This fact may decrease the priority for timely implementation, which in any case has been delayed until after start-up.

Area: Component Integrity

RPV Embrittlement and Its Monitoring is still a safety relevant problem for all WWER-1000 reactors and has not yet been resolved sufficiently. Only limited solutions appear possible.

Non-Destructive Testing is an essential tool to monitor the status of materials and has not yet been fully introduced in NPPs with WWER-1000 reactors. Critical regions exist where current NDT methods are not applicable due to restricted accessability. The material status of such regions are extremely difficult to assess reliably.

Concerning the issue of *Steam Generator Collector Integrity,* the steam generators manufactured for K2/R4 are improperly designed. Despite all efforts they continue to show a strong likelihood for failure[13], which may result in an uncontrolled containment bypass.

Steam and Feedwater Piping Integrity are highly impaired due to insufficient design (insufficient physical separation). Only very cost-intensive hardware measures,

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[12] Atomaudit disputes this (Atomaudit, 1997), but no supporting technical information was made available.

[13] Atomaudit disputes this (Atomaudit, 1997), but no supporting technical information was made available.

which have not yet been taken into consideration, have the potential to overcome this safety relevant problem.

Area: Systems

Only a complete redesign along with the use of advanced materials and fixing technologies for the insulation would potentially overcome the problem of *ECCS Sump Screen Blocking*. The intent is to replace the existing thermal insulation, although the replacement is untested.

Replacement of *Steam Generator Safety and Relief Valves* is mandatory for the steam generators in order to manage the possible fluid phases from steam to water under all emergency and accident conditions. Initially only qualification of existing valves for release of steam-water mixtures or water is planned.

Concerning the issue *Reactor Vessel Head Leak Monitoring System "the intent of the recommendations will be met*" according to IAEA. The proposed installation of a reactor vessel head leak monitoring system likely would resolve the issue.

Area: Electrical Power

The issue of insufficient *Emergency Battery Discharge Time* can readily be solved by the planned measure.

Aging and Residual Life Time of Cables are not addressed in the Ukrainian Modernization Programme. In view of improper mothballing, it is strongly recommended to investigate the aging situation of all installed cables in order to determine whether replacement is necessary.

Area: Containment

The WWER-100/V-320 containment appears to have a generic potential for severe accident vulnerability. Redesign might not be possible.

The likelihood of *Containment Bypass* is inherent to WWER-1000s due to an unfavorable steam generator design. Among others, this was underlined by the Balakovo event in 1996.

Concerning the issue of *Containment Structure*, the problem with tension losses in the prestressing cables of the containment is not addressed in the Ukrainian Modernization Programme for K2/R4. In contradiction to Riskaudit, IRR recommends calculations and appropriate measures to improve the situation before rather than after start up of the reactors.

Area: Internal Hazards

For the issue of *Fire Prevention*, IRR recommends PSA as a minimum requirement. This would allow to quantify the effective increase in safety due to specific measures.

The issue of *Pipeline Breaks Impact Inside the Reactor Building* is addressed in the Ukrainian Modernization Programme. A comprehensive analysis is necessary to obtain an overview of the situation and to develop corresponding measures. The restraints of the existing design may in some cases hamper implementation.

High Energy Pipe Ruptures are partly but insufficiently addressed in the Ukrainian Modernization Programme. Additional analytical efforts are necessary to obtain an overview of the possible reasons and consequences of high energy pipe ruptures. Measures should be based on this assessment.

Area: External Hazards

The issue of *Extreme Weather Conditions* is only partly addressed in the Ukrainian Modernization Programme. It might gain significant safety relevance, e.g. for emergency cooling water tanks. The related heating system must be able to cope with all low temperature situations.

Man-induced External Hazards and Seismicity are not yet or only partially taken into account. They must be included in their entirety into a site-specific modernization programme.

Area: Accident Analysis

Plant-specific *PSAs* have not been performed for K2 and R4. The proposed Modernization Programme is not based on probabilistic results and criteria, but merely on practical experience and deterministic assumptions. Using a PSA as a tool in an early stage of plant history - in this case for properly assembling the Modernization Programme - is highly recommended by IRR.

The issue of *Rapid Reactivity Increase* has not been addressed to date. The need to obtain a negative temperature reactivity coefficient by using inserted control rod groups for the first fuel cycle represents a design deficiency of WWER-1000 reactors. Thus a complete set of rod ejection analyses must be conducted for the start-up phase of operation of K2 and R4, taking into consideration the potential severity of this type of accident.

Area: Spent Fuel and Radioactive Waste

The area of *Spent Fuel Storage and Radioactive Waste Management* is not included in the Ukrainian Modernization Programme. The back-end of the Ukrainian nuclear fuel cycle remains indefinite.

Post-TMI Requirements

The *Post-TMI Requirements* are not fully addressed in the Modernization Programme. It is recommended that the as yet unaddressed Post-TMI requirements be included.

Norms and Standards

Even in the upgraded form, K2 and R4 will not completely fulfill the current Russian safety regulations OPB-88, corresponding to Western safety standards. These two units will therefore fail to meet Western safety standards in essential points.

Zaporozhe and Temelin NPP

The approaches to completing WWER-1000/V-320s range from *Zaporozhe 6 NPP* in Ukraine to *Temelin* in the Czech Republic: the former was completed without Western funds and technical cooperation, while the latter is being upgraded with the intensive help of U.S. technology, equipment and financing.

Both options are confronted with significant technical problems. Neither is satisfactory from the safety (not to mention economic) point of view and neither can be taken as an encouraging example for the completion of K2/R4.

Viability of the K2/R4 Modernization Programme

Any adequate evaluation of the safety relevant aspects of nuclear power technology requires transcending mere technical considerations due to the mutual interdependencies of technical, logistic, infrastructural and economic factors. This interdisciplinary approach also dictates devoting some attention to the financial environment. In this light, the estimated time frame and costs of the K2/R4 Modernization Programme are unreliable and incomplete due to assessment uncertainties. Beyond the technical issue, any financing programme based on the present incomplete information may increase rather than reduce nuclear safety problems.

Final Conclusion

A great number of unresolved safety relevant issues argues against pursuing the K2/R4 completion project.

Even in the upgraded form, K2 and R4 will not fulfill the current Russian safety regulations and will fail to meet Western safety standards in essential points.

Solving the Ukrainian problems of logistics and infrastructure may be even more difficult than finding engineering solutions for the wide range of technical shortcomings in the area of nuclear safety. Although a realistic estimate is beyond the scope of this study, the required funds and time will clearly by far exceed all projected limits.

Less risky energy saving or/and alternative power generation technologies should be considered.

Abbreviations

Abbreviations

ABB	Asea Brown Bovery
AC	Alternating Current
AEA-T	AEA - Technology
ALARA	As Low As Reasonable Achievable
ATWS	Anticipated Transients Without Scram
BDBA	Beyond Design Base Accident
BRU-A	Steam dump to the atmosphere
CDF	Core Damage Frequency
CEZ	Ceske Elektrarne Zavody (Czechian Electricity Company)
CF	Capacity Factor
CPS	Control and Protection system
DBA	Design Base Accident
DC	Direct Current
DOE	Department of Energy
EBRD	European Bank for Reconstruction and Development
EC	European Commission
ECC	Emergency Core Cooling
ECCS	Emergency Core Cooling System
EDF	Electricite de France
EIA	Environmental Impact Assessment
GDP	Gross Industrial Production
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
INES	International Nuclear Event Scale
INSAG	International Nuclear Safety Advisory Group
IRR	Institute of Risk Research
ISI	In-service Inspection
K2/R4	Khmelnitsky 2 / Rovno 4
LBB	Leak Before Break
LOCA	Loss of Coolant Accident
MCP	Main Coolant Pump
Minenergo	Ministry of Power and Electrification
MOHT	Association of Russian Organizations Including: Atomenergoproject, OKG Gidropress, Kurchatov Institute, VNIIAES, Rosenergoatom, etc.
MoU	Memorandum of Understanding
MP	Modernization Programme
NDE	Non Destructive Examination
NDT	Non Destructive Testing
NPP	Nuclear Power Plant
NRA	Nuclear Regulatory Authority
NRC	Nuclear Regulatory Commission
NUSS	Nuclear Safety Standards

PISC	Programme for Inspection of Steel Components
PPP	Public Participation Procedure
PRIS	Power Reactor Information System
PSA	Probabilistic Safety Analysis
PWR	Pressurized Water Reactors
QA	Quality Assurance
RBMK	Graphite-moderated Water-cooled Channel Reactor
RP	Radio - Protection
RPV	Reactor Pressure Vessel
RTZO	Electrical Distribution Board
SAR	Safety Analysis Report
SG	Steam Generator
SPDF	System for Pipeline Dynamic Fastening
STC	Scientific Technical Center on Nuclear and Radiation Safety of Ukraine
TACIS/PHARE	European Union Assistance Programme for Central and Eastern European Countries and the Newly Independent States
TMI	Three Mile Island
TOB	Safety Analysis Report, Russian Federation
TSO	Technical Safety Organization
VVER	see also WWER
WWER	Water-moderated Water-cooled Energy Reactor

References

References

Atomaudit, 1997 — Comments on the Draft Report of IRR “Safety Relevant Issues and Measures: Khmelnitsky-2 and Rovno-4 NPPs” Kiev, June 1997

Battelle, 1996 — European Bank for Reconstruction and Development paper. Ukraine power Sector Least Cost Investment Plan and Training Programme: Main Report, Battelle Pacific Northwest Laboratories, 1996.

CEE, 1986 — CEE Bankwatch Network Briefing, 1996.

CEZ, 1997 — Press Conference of CEZ on April 29. 1997, Hospodarske Noviny, June 2, 1997.

Chesshire, 1997 — Demand and Energy Efficiency, Supporting Paper for the Ukraine Project: J. Chesshire, SPRU, 1997.

DOE, 1987 — Overall Plant Design Descriptions, WWER, Water-Cooled, Water-Moderated Energy Reactor, DOE/NE-0084 Revision 1, Department of Energy, October 1987.

DOE et al., 1994 — U.S./Ukraine Evaluation of Energy Options to Replace the Chernobyl Nuclear Plant, U.S. DOE / Ukrainian Goskomatom and Ukrainian Ministry of Energy; June 23, 1994.

EC, 1994 — EC Council Document 7557/94.

Goskomatom, 1995 — Application for funding for the completion of the Ukrainian nuclear power units Rovno 4 and Khmelnitsky 2, Goskomatom, 1995.

GRS, 1993 — Sicherheitstechnische Bewertung des Kernkraftwerkes Stendal, Block A, vom Typ WWER-1000/W-320, Gesellschaft für Anlagen und Reaktorsicherheit (GRS), Mai 1993.

Heindler et al., 1996 — Technical Memorandum Regarding the Temelin Nuclear Power Plant, Update 1996, Vienna, 1996.

IAEA, 1993 WWER-1000/V-320 Generic Safety Issues Developed from Codes and Standards Comparison, IAEA-SC-071, Ch. Lin auth., SAS/NENS/IAEA, Vienna, April 1993.

IAEA-K2, 1997 Report of an Expert´s Mission to Review the Modernization Programme of Khmelnitsky NPP Unit 2, Ukraine, 10.- 14. June 1996, IAEA-RU-6131, WWER-SC-178, February 1997.

IAEA-R4, 1995 Report of an Experts' Mission to Review the Modernization Programme of Rovno NPP Unit 4, Ukraine, 2 to 12 October 1995, IAEA-TA-2486, WWER-SC-151, March 1996.

IAEA, 1996 Safety Issues and Their Ranking for WWER-1000 Model 320 Nuclear Power Plants, IAEA-EBP-WWER-05, March 1996.

IAEA/NEA IRS, 1997 Event Report: Steam Generator Tubes Damage Due to Breach of Secondary Water Chemistry in 1996 at Balakovo NPP, Unit 2 (The Russion Federation), IAEA/NEA Incident Report System, 1997 Joint Meeting to Exchange Information on Recent Events in Nuclear Power Plants, Vienna, Austria, 26.-30. May 1997.

IEA, 1996 Energy Policies of Ukraine: 1996 Survey, IEA/OECD, Paris, 1996.

INSAG-3, 1988 Basic Safety Principles for Nuclear Power Plants, A Report By the International Nuclear Safety Advisory Group, IAEA, Vienna, 1988.

Kemeny et al., 1979 “Report of the President´s Commission on the Accident at Three Mile Island”, Kemeny et al., Washington, 1979.

Kirmse et al., 1996 Methods for the Evaluation of Safety Measures and Their Application to WWER-1000/V-320 Nuclear Power Plants, Kirmse, R., Mertins, M., Richter, W., Zabka, H., GRS, 1996.

Khmelnitsky, 1993 Khmelnitsky Unit 3, A Complex Project of Backfitting and Completion, Preliminary Feasibility Study, 1993.

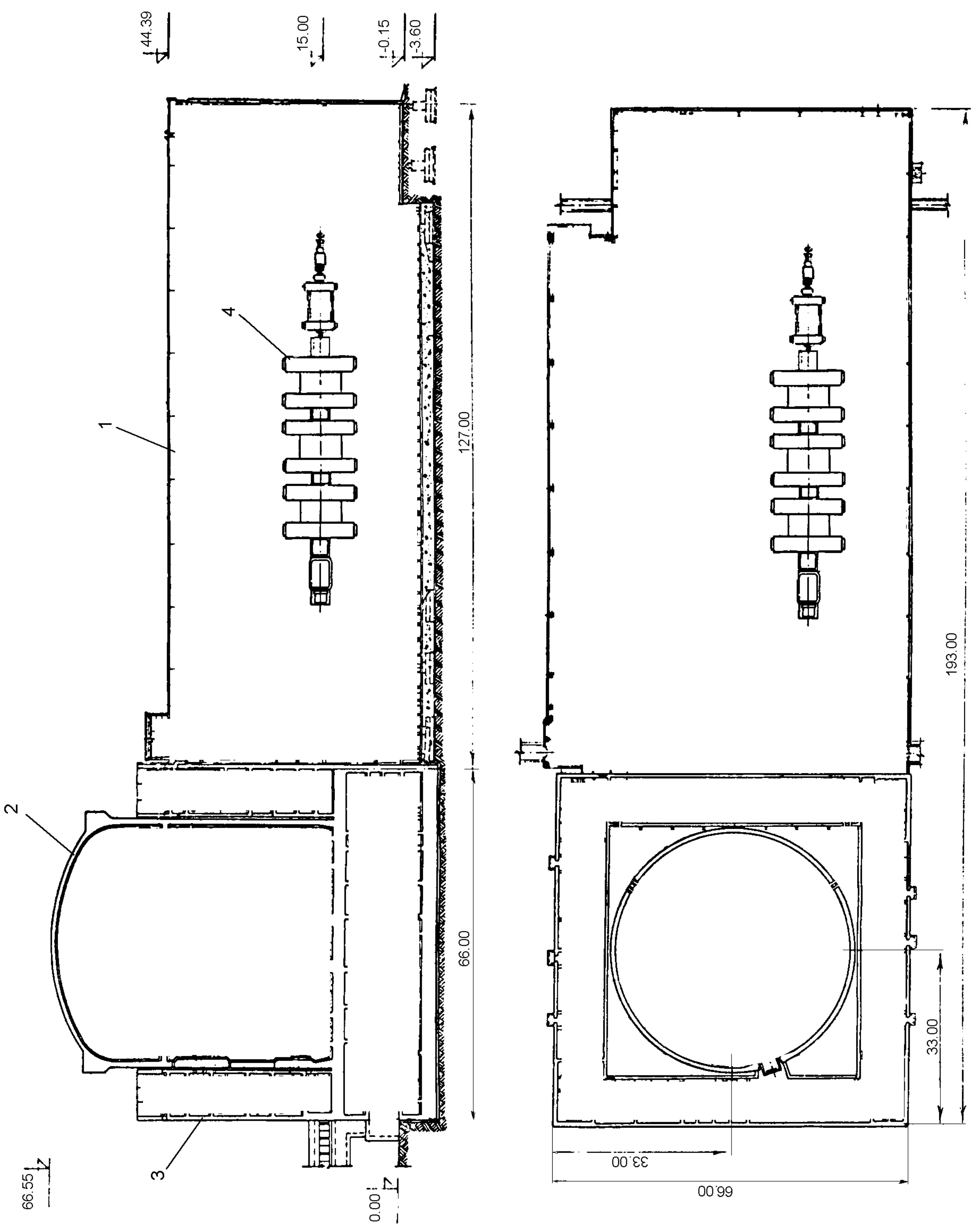
Kiev Institute et al., 1996 Modernization Programmes for the Ukrainian Nuclear Power Plants with WWER-1000 (B-320);
Revision 1, Consortium KIEP-MOHT-ENAG, 6/1996;
Revision 2, Kiev Institute Energoproject, 11/1996.

Kopchinsky et al., 1996	Nuclear Energy in Ukraine. Statute and Problems, G. Kopchinsky, M. Mikolaitchouk, N. Steinberg, Atomaudit, LTD., Kiev, Ukraine, 1996.
Lederman, 1996	The Role of PSA to Improve Safety of Nuclear Power Plants in Eastern Europe and in Countries of the Former Soviet Union, L. Lederman, J. Höhn, IAEA, Probabilistic safety assessment and management '96 ESREL'96 - PSAM-III, June 24-28 1996, Crete, Greece.
MHB, 1989	Severe Accidents at the Three Mile Island Unit 1, MHB Technical Associates, San Jose, California, 1989.
MOHT-EDF, 1996	Generic Reference Program for the Modernization of WWER-1000/V-320, MOHT OTJIG RM-EDF DE CLI, Revision 5, January 1996.
NE Int., 1994	Nuclear Engineering International, Vol. 39, No. 474, January 1994, pp. 41.
NW, 1995a	Nucleonics Week, March 15, 1995.
NW, 1995b	Nucleonics Week, July 20, 1995.
NW, 1995c	Nucleonics Week, July 27, 1995.
Phare/Tacis, 1996	The European Union’s Nuclear Safety Programme in the Central and Eastern European Countries and New Independent States, published by the European Commission, update 1996.
Riskaudit, 1996	Evaluation of the Modernization Programme of Rovno 4 and Khmelnitsky 2 Units, Riskaudit, 1996.
Riskaudit, 1997	Modernization Project Kozloduy 5&6, Riskaudit, 1997.
Shteynberg et al., 1991	Causes and Circumstances of the Accident at Unit 4 of the Chernobyl Nuclear Power Plant on 26. April 1986, N. A. Shteynberg et al., Report by a Commission to the USSR State Committee for the Supervision of Safety in Industry and Nuclear Power, Moscow, 1991.
Smyshlyayev, 1996	Establishment of Nuclear Safety Regulatory Regime in Ukraine (Lessons of Chernobyl), A. Smyshlyayev, IAEA, Vienna, April 1-3, 1996.

Stone&Webster, 1997	System Optimal Expansion Study, Report of the Results, Stone&Webster Management Consultants, Inc., April, 1997.
Sussex, 1997	Economic Assessment of the Khmelnitsky 2 and Rovno 4 Nuclear Reactors in Ukraine, Science Policy Research Unit, University of Sussex, 4th February 1997.
Tolstonogov, 1996	Specific Programs to Improve the Safety Level of Chernobyl NPP. V. Tolstonogov, International Forum “One Decade After Chernobyl: Nuclear Safety Aspects” organized by the IAEA, Vienna, April 1-3, 1996.
Umanets, 1996	Problems and Necessary Conditions of the Safe Shutdown and Decommissioning of Chernobyl Nuclear Power Plant, M. Umanets, International Forum “One Decade After Chernobyl: Nuclear Safety Aspects” organized by the IAEA, Vienna, April 1-3, 1996.

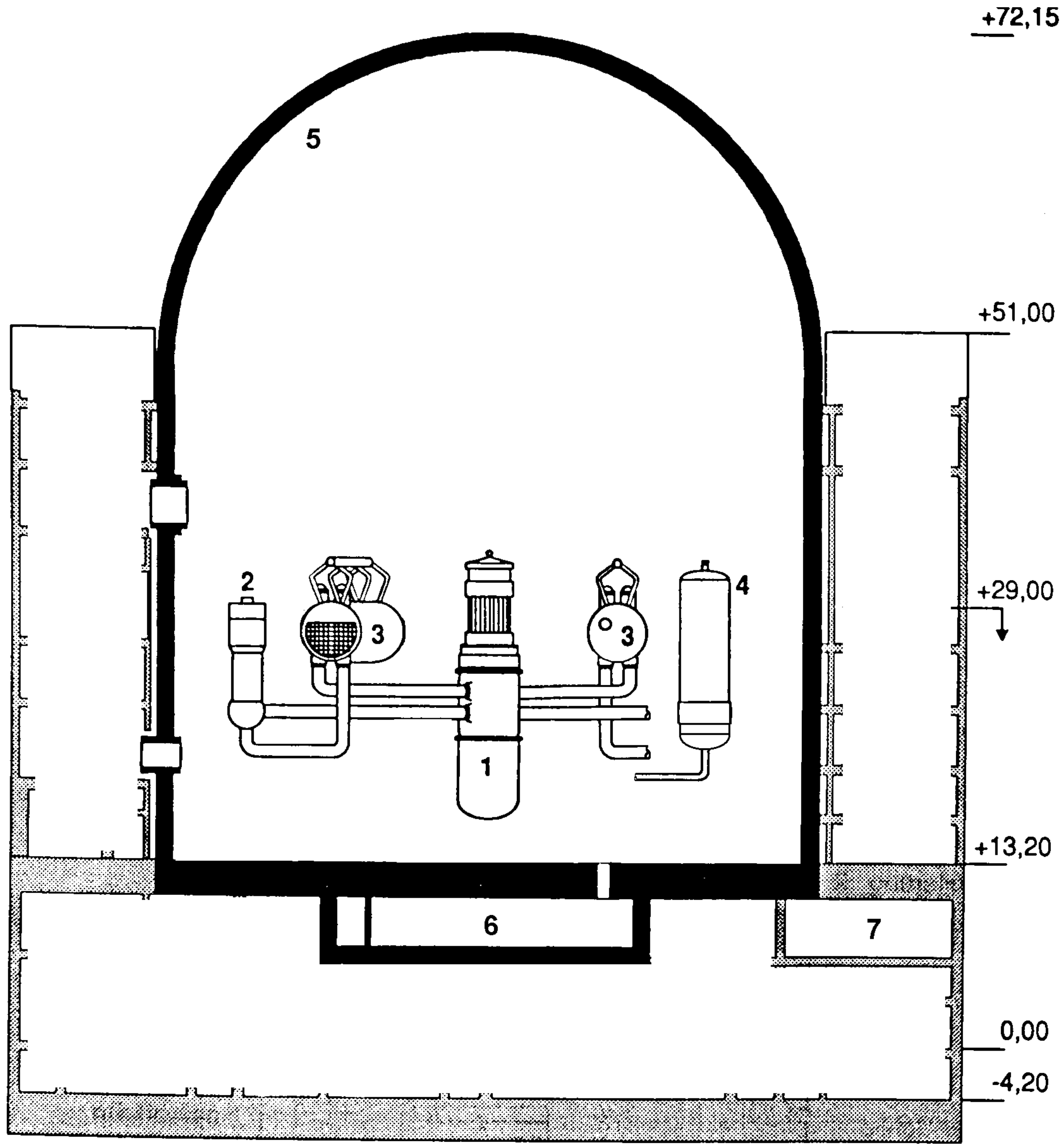
Figures

Simplified after (GRS, 1993) and (DOE, 1987)



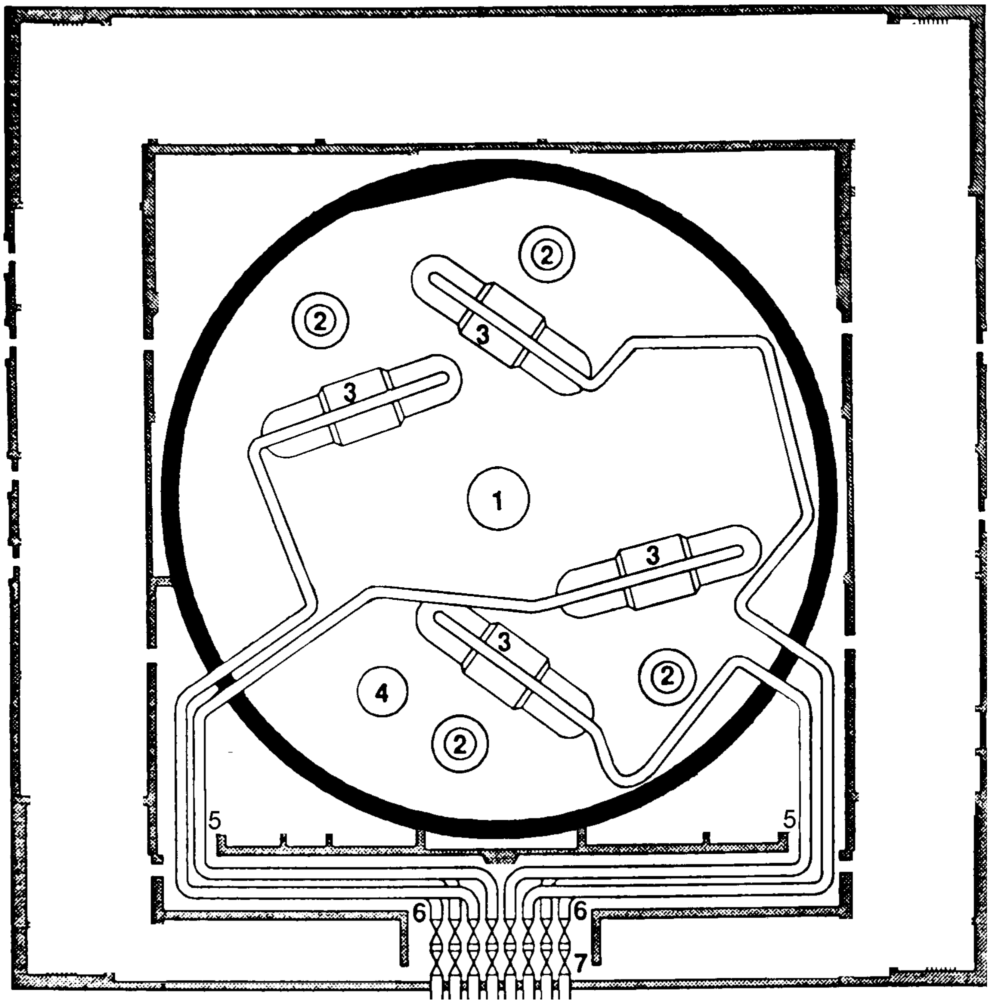
1. Turbine Building
2. Containment Shell
3. Auxiliary and Shield Building
4. Turbine

Figure 1 Reactor Building and Turbine Hall - Elevation and Plan View



1. Reactor Pressure Vessel
2. Primary Coolant Pump
3. Steam Generator
4. Pressurizer
5. Containment
6. Boric Acid Tank
7. Main Control Room

Figure 2 Reactor Building with Containment - Elevation View



1. Reactor Pressure Vessel
2. Primary Coolant Pump
3. Steam Generator
4. Pressurizer
5. Main Steam Line
6. Feedwater Line
7. BRU-A

Figure 3 Reactor Building with Containment - Plan View (29.00 m Elevation)

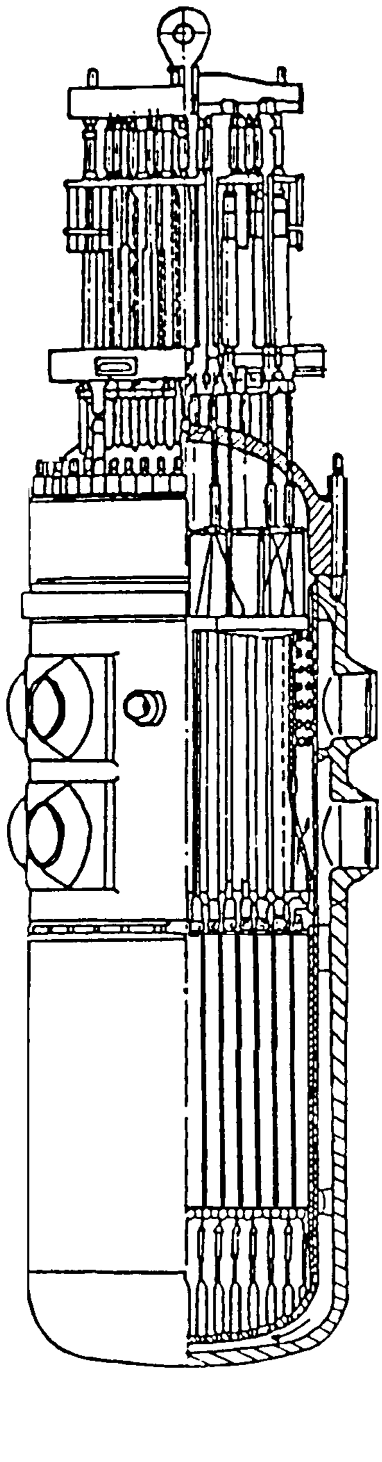


Figure 4 Reactor Pressure Vessel with Internals

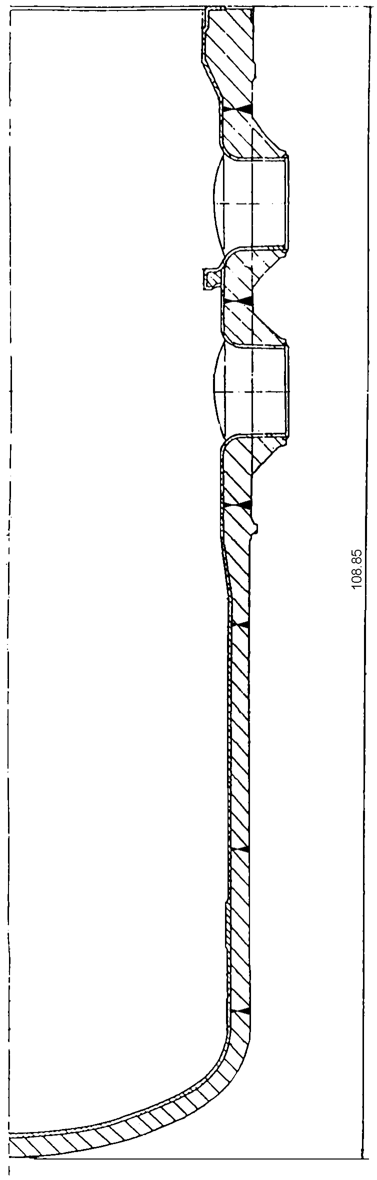


Figure 5 Reactor Pressure Vessel with Main Weldments

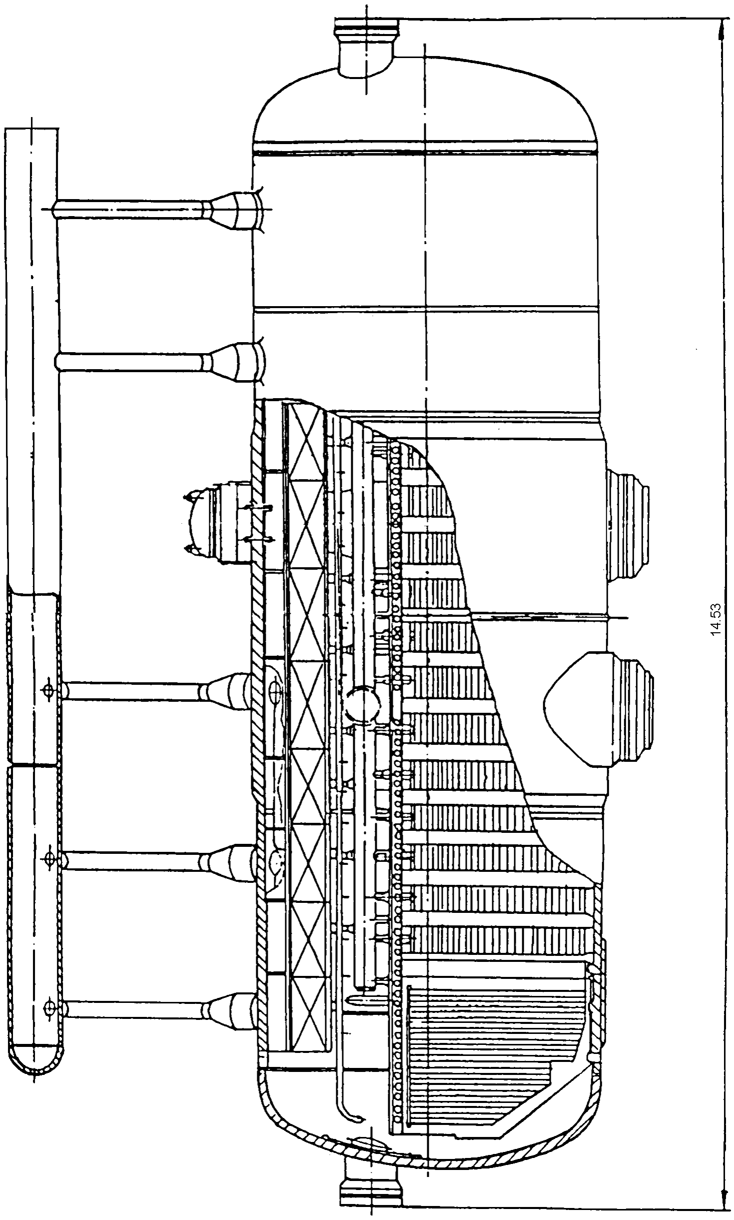


Figure 6 Steam Generator

Attachment 1: Table of Generic Safety Issues and their Ranking for WWER-1000 Model 320 NPPs

Extracted from (IAEA, 1996)

Attachment 1: Table of Generic Safety Issues and their Ranking for WWER-1000 Model 320 NPPs

Extracted from (IAEA, 1996):

The identification of safety issues is based on safety studies conducted by the operators of WWER-1000/V-320 units and by organizations dealing with these reactors, on findings of IAEA safety missions to WWER-1000/V-320 plants and on information obtained from specialists from various countries during the IAEA consultants meetings organized in 1992-1995 within the framework of the Extrabudgetary Programme on the Safety of WWER and RBMK NPPs.

The following safety issues are deviations from currently recognized safety practices in design and operation judged to be safety significant by their impact on plants' defense in depth.

Altogether *84* safety issues have been identified, of which *11* are in *Category III* (defense in depth is insufficient, immediate corrective action is necessary), *38* in *Category II* (defense in depth is degraded, action is needed to resolve the issue) and *22* in *Category I* (departure from international practices, to be addressed as part of actions to resolve higher priority issues). In the case of operational safety issues (*13* safety issues) no ranking is provided, as the available material was considered insufficient.

These generic safety issues are intended as a reference for the development of plant-specific safety improvement programmes and for the evaluation of measures proposed and/or implemented.

The Modernization Programme of the IAEA for K2 and R4 (IAEA-K2, 1997; IAEA-R4, 1995) is based on these generic safety issues.

Issue No.	Issue Title	Issue Rank
AREA: GENERAL		
G1	Classification of components	II
G2	Qualification of equipment	III
G3	Reliability analysis of safety class 1 and 2 systems	II
AREA: CORE		
RC1	Prevention of inadvertent boron dilution	II

RC2	Control rod insertion reliability/Fuel assembly deformation	III
RC3	Subcritically monitoring during reactor shutdown conditions	II
AREA: COMPONENT INTEGRITY		
CI1	RPV embrittlement and its monitoring	III
CI2	Non-destructive testing	III
CI3	Primary pipe whip restraints	II
CI4	Steam generator collector integrity	III
CI5	Steam generator tube integrity	II
CI6	Steam and feedwater piping integrity	III
AREA: SYSTEMS		
S1	Primary circuit cold overpressure protection	II
S2	Mitigation of a steam generator primary collector break	II
S3	Reactor coolant pump seal cooling system	II
S4	Pressurizer safety and relief valves' qualification for water flow	II
S5	ECCS sump screen blocking	III
S6	ECCS water storage tank and suction line integrity	II
S7	ECCS heat exchanger integrity	II
S8	Power operated valves on the ECCS injection lines	I
S9	Steam generator safety and relief valves' qualification for water flow	III
S10	Steam generator safety valves' performance at low pressure	II
S11	Steam generator level control valves	I
S12	Emergency feedwater makeup procedures	I
S13	Cold emergency feedwater supply to SG	I
S14	Ventilation system of control rooms	II
S15	Hydrogen removal system	II

AREA: INSTRUMENTATION AND CONTROL		
I&C1	I&C reliability	II
I&C2	Safety system actuation design	I
I&C3	Automatic reactor protection for power distribution and DNB	I
I&C4	Human engineering of control rooms	II
I&C5	Control and monitoring of power distributions in load follow mode	II
I&C6	Condition monitoring for the mechanical equipment	I
I&C7	Primary circuit diagnostic systems	II
I&C8	Reactor vessel head leak monitoring system	III
I&C9	Accident monitoring instrumentation	II
I&C10	Technical support center	II
I&C11	Water chemistry control and monitoring equipment (primary and secondary)	I
AREA: ELECTRICAL POWER		
El1	Off-site power supply via startup transformers	I
El2	Diesel generator reliability	I
El3	Protection signals for emergency diesel generators	I
El4	On-site power supply for incident and accident management	II
El5	Emergency battery discharge time	III
El6	Ground faults in DC circuits	I
AREA: CONTAINMENT		
Cont.1	Containment bypass	II
AREA: INTERNAL HAZARDS		
IH1	Systematic fire hazards analysis	II
IH2	Fire prevention	III
IH3	Fire detection and extinguishing	II
IH4	Mitigation of fire effects	II

IH5	Systematic flooding analysis	I
IH6	Protection against flood for emergency electric power distribution boards	II
IH7	Protection against the dynamic effects of main steam and feedwater line breaks	II
IH8	Polar crane interlocking	II
AREA: EXTERNAL HAZARDS		
EH1	Seismic design	II
EH2	Analyses of plant specific natural external conditions	I
EH3	Man-induced external events	II
AREA: ACCIDENT ANALYSIS		
AA1	Scope and methodology of accident analysis	II
AA2	QA of plant data used in accident analysis	I
AA3	Computer code and plant model validation	I
AA4	Availability of accident analysis results for supporting plant operation	I
AA5	Main steam line break analysis	I
AA6	Overcooling transients related to pressurized thermal shock	II
AA7	Steam generator collector rupture analysis	II
AA8	Accidents under low power and shutdown(LPS) conditions	II
AA9	Severe accidents	I
AA10	Probabilistic safety assessment (PSA)	I
AA11	Boron dilution accidents	I
AA12	Spent fuel cask drop accidents	I
AA13	Anticipated transients without scram (ATWS)	II
AA14	Total loss of electrical power	II
AA15	Total loss of heat sink	II

AREA: OPERATION		
OP1	Procedures for normal operation	
OP2	Emergency operating procedures	
OP3	Limits and conditions	
Ma1	Need for safety culture improvements	
Ma2	Experience feedback	
Ma3	Quality assurance programme	
Ma4	Data and document management	
PO1	Philosophy on use of procedures	
PO2	Surveillance programme	
PO3	Communication system	
RP1	Radiation protection and monitoring	
Tr1	Training programmes	
EP1	Emergency center	

Attachment 2: Ukrainian Modernization Measures

Extracted from (Kiev Institute et al., 1996)

Attachment 2: Ukrainian Modernization Measures

The following safety, availability and operational issues are extracted from the Ukrainian Modernization Programme for Khmelnitsky 2 and Rovno 4. See (Kiev Institute et al., 1996).

1	**SAFFETY**	**RANK**
1.1	**GENERAL**	
	• Components qualification	2
1.2	**REACTOR CORE AND FUEL HANDLING**	
	• Neutronic characteristics of the core	2
	• Core structure	3
1.3	**COMPONENTS INTEGRITY**	
	• Primary circuit system	2
	• Safety significant systems under pressure	2
	• Reactor (with vessel)	3
	• Other	3
1.4	**SYSTEMS**	
	• Reactivity maintenance	2
	• Primary circuit coolant margin maintenance	2
	• Primary circuit cooling	2
	• Primary circuit pressure maintenance	2
	• Containment isolation	
	• Auxiliary systems	2
1.5	**MONITORING AND CONTROL SYSTEM**	
	• Information system	3
	• Reactor control and protection system	3
	• Control system	2
	• Monitoring system	2
1.6	**ELECTRICAL POWER SUPPLY**	
	• Electrical power generation and transformation	2
	• Electrical power distribution	2

1.7 CONTAINMENT AND BUILDING STRUCTURES

• Containment bypass risk	2
• Integrity	2

1.8 INTERNAL HAZARDS

• Fire hazard protection	3
• Flooding protection	2
• Hazards due pipes rupture missiles	2

1.9 EXTERNAL HAZARDS

• Seismicity	2
• Natural external conditions	2
• External technogenic	1

1.10 ACCIDENTS ANALYSIS

• Design basis accident	2
• Beyond the design basis accident	2
• Additional safety analysis	2
• Probabilistic safety analysis	1

2 AVAILABILITY

2.1 FUEL HANDLING

• Fuel handling control	2

2.2 PRIMARY CIRCUIT

• Main circulation pumps	2
• Integrity	1

2.3 SECONDARY CIRCUIT

• Steam generators	2
• Other component	2
• Steam and water system	2

2.4 MONITORING AND CONTROL SYSTEM

• Diagnostic systems	3

2.5 ELECTRICAL POWER SYSTEMS

	• Diagnostic facilities	2
	• Electrical power distribution	2
	• Electric power output systems	2
	• Electric power generation and transformation	2
2.6	**REACTOR CORE AND FUEL**	
	• Neutronic design of core	2
2.7	**COMPONENTS INTEGRITY**	
	• Chemistry conditions	2
	• Miscellaneous	1
2.8	**SYSTEMS**	
	• Pressure maintenance inside containment	2
	• Containment integrity	2
2.9	**CONTROL AND MONITORING SYSTEM**	
	• Monitoring and diagnostic system	2
	• Reactor control and protection system	2
	• Information system	2
	• Operators support system	2
2.10	**INTERNAL HAZARDS**	
	• Fire prevention	2

3 OPERATION

3.1	**OPERATION PROCEDURES**	
	• Normal operation procedures	2
	• Accident operation procedures	2
3.2	**CONTROL**	
	• Use of operation experience and data base	1
	• Quality assurance program	1
	• Documents development	2
3.3	**TESTS AND DIAGNOSTICS**	
	• Periodic test programme	2

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Report 1	Kromp W. et al. (1992): Visits to NPP Krsko June/July 1992.
Report 2	Kromp W. et al. (1992): Literature Review.
Report 3	Kromp W. et al. (1993): A Plan for Evaluating the Safety of NPP Krsko.
Report 4	Seidelberger E. et al (1994): Evaluation of Safety Relevant Systems and Procedures at NPP Krsko. ICISA Documentation I
Report 5	Kromp W. et. al (1993): Evaluation of Safety Relevant Components and Materials in NPP Krsko. ICISA Documentation II.
Report 6	Lambright J. (1993): Evaluation of Fire Protection at NPP Krsko: Analysis of Core Damage Frequency Due to Fire at the Krsko Nuclear Power Plant. ICISA Documentation III.
Report 7/8	Kromp W. et al. (1995): Evaluation of Seismic Risk of the Site, Components and Structures at NPP Krsko. ICISA Documentation IV.
Report 9	Andreev I. et al. (1994): Interdisciplinary Extension of the Safety Review for NPP Krsko: Summary of the Safety Studies for NPP Krsko. ICISA Documentation V. *(in preparation)*
Report 10	Kromp W. et al. (1994): Analyse der Sicherheitsaspekte des geplanten Brennelemente-Zwischenlagers im Areal des KKW Dukovany.
Report 11	Kromp-Kolb H. et al. (1994): Vorprojekt: Katastrophenpläne für Schulen im Falle atomarer Unfälle.
Report 12	Kromp W. et al. (1995): Public Participation Procedure NPP Mochovce: Walkdown, Important Follow-up Meetings and Preliminary Evaluation of the Riskaudit Report.
Report 13	Kromp W. et al. (1997): WWER-1000 Reconstruction and Completion. Safety Issues and Suggested Solutions: Comparative Tables.