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EXEMPLE D'ASSISTANCE INTERNATIONALE
CAS DE LA BULGARIE
ACTION DU CONSORTIUM

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Sûreté des Réacteurs VVER
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LA SURETE DES REACTEURS VVER

RAPPORT

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Exemple d'assistance internationale

Cas de la Bulgarie

Action du Consortium

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I - INTRODUCTION

The safety status achieved last year at the Kozloduy Nuclear Power Plant (NPP) and the capability of the Bulgarian Nuclear Safety Authority (BNSA) to assess the safety of the plant and the adequacy of proposed improvements have been matters of international concern. However, the Kozloduy NPP contributes 35-40 per cent of the electrical generating capacity in Bulgaria. For further operation of the plants, it is, therefore, essential that safety is improved.

In July 1991, the Commission of the European Communities (CEC) instituted a Six Months Emergency Action Programme for Bulgaria under the PHARE regional nuclear safety programme. The programme consisted of three parts :

- an industrial emergency programme supporting the utility of the Kozloduy NPP,
- a study to evaluate Bulgaria's electricity needs,
- technical assistance for reinforcement of the Bulgarian Nuclear Safety Authority.

For the third part, complementary to the industrial emergency programme carried out by the WANO (World Association of Nuclear Operators), a Consortium of expert institutions and regulatory from EC member states was established by CEC for assistance to BNSA.

The Consortium consisted of :

- Institut de Protection et de Sûreté Nucléaire (IPSN), France, technical support of the French regulatory body
- Gesellschaft für Anlagen und Reaktorsicherheit (GRS) mbH, Germany, an organisation in safety engineering, technical support of governmental regulatory body
- AIB-Vinçotte Nuclear (AVN), Belgium, the organisation authorised by the Belgian Government for licensing and inspection of nuclear power plants
- UK Atomic Energy Authority (AEA Technology), an independent UK Government owned nuclear R & D and consultancy organisation.
- Nuclear Installations Inspectorate (NII) of the Health and Safety Executive, United Kingdom, the nuclear regulatory body for the United Kingdom

II - WORKING PROGRAMME

In addition to the assistance to the BNSA to develop and to improve its regulatory structures, the working programme of the Consortium consisted in the following main parts :

- In first, in order to help the BNSA to complement and make specific to Kozloduy NPP units 1 to 4 the conclusions of the IAEA (International Atomic Energy Agency) extrabudgetory programme on the VVER 440/V 230, the Consortium performed a specific safety review of these plants on both design and operational aspects. A detailed safety evaluation report specific to the problems of Kozloduy is now available.
- Since autumn 1991, units 1 and 2 have been shut down. At the end of November 1991, the utility presented proposals in the form of an outage programme for restoring systems and upgrading operational safety of these units before restarting operation. This NPP programme had three main objectives :
  - recover the original status of the plant.
    It concerns the housekeeping activities, the in service inspection of main components, and the annealing of the reactor pressure vessel,
  - upgrade the original operational safety of the plant.
    It concerns the management, organisation and administration of the plant, the training of the NPP staff , the operation manuals, the maintenance policy, the radiation protection policy and the emergency preparedness,
  - upgrade the original design safety of the plant.
    It concerns the performance of studies, the implementation of modifications and the requalification of safety systems.

So, in second, the Consortium provided some assistance to the BNSA to review the content of this outage programme and took this opportunity to help the BNSA to implement a licensing process for the review of this document. Technical recommendations based on the safety evaluation report were proposed by the Consortium to the BNSA, and then, discussed during licensing meetings with the NPP staff assisted by the WANO team. Result of this process consisted in a revision of the outage programme in June 92 and in a serie of complementary BNSA requests to NPP.

• After a partial implementation of the outage programme, and the performance by the utility of a "synthesis report", the unit 2 of the Kozloduy NPP is now intended to be restarted within a few weeks. In order to analyse the safety level of the plant, the BNSA required to receive some Consortium advises. Assistance for inspections and for technical review of the new status of the plant constitute the third part of the Consortium action. This process is now underway.

To complete this presentation, we will present in the following chapter the approach used by the Consortium in order to judge on the acceptability of the programme and of its fulfilment.

III - APPROACH USED BY THE CONSORTIUM

A strict appliance of Western rules for the review of the outage programme would require large-scale reconstruction of safety systems and even adding new ones. So, the analysis was performed under the basic assumption that time of operation was limited.

A specific approach was defined by the Consortium in order to be able to judge on the acceptability of the programme and of its fulfilment :

- based on the conventional list of transients and accidents used in Western countries, on international operating experience and on Western PSA (Probabilistic Safety Analysis) studies, the orientation of Consortium's action was as follows :

(i) for the most probable events, to improve the systems in normal operation and the safety systems associated with these accidents in order to mitigate their consequences.

Among the main actions recommended by the Consortium and in good way of being fulfilled by the NPP, we can mention:

- improvements of the systems used during normal operation,
- provision for additional scram signals,
- checking of availability of reactor scram components,
- improvements to the reliability of the safety systems and of support systems by:
  - addressing the most important weak points regarding the single failure criterion.
  - carrying out in service inspections on the main safety systems,
  - developing an improved periodical test program,
  - developing administrative procedures to guarantee their availability.
  - developing prevention against common mode failure:
    - flooding : implementation of signalling and of a drainage pump system,
    - fire : protection of cables.

(ii) for the less probable events, to reduce the frequency of occurrence by the use of preventive measures and to develop accident procedures to deal with them.

Among the main actions performed by the NPP and recommended by the Consortium, we can mention:

- 100 % testing of the main components :

    - vessel,
    - pressuriser and connected lines,
    - primary loops,
    - primary components (Main Coolant Pumps, Steam Generators),
    - main steam lines,
    - main feed water lines,

- implementation of normal procedures to follow in the case of:

    - abnormal leakage of the primary circuit,
    - abnormal leakage from primary to secondary circuit,
    - abnormal leakage in heat-exchangers to avoid dilution of primary coolant.

- implementation of accidental procedures for accidental situations covered by existing design basis accident.

(iii) for some of the beyond-design-basis accidents, to develop a strategy in order to reduce their consequences, using realistic assumptions.

We can mention:

- study and implementation of a procedure dealing with the case of a break in an injection line of the HPIS (High Pressure Inspection System),

- study and implementation of procedures to cope with losses of main feed water system and auxiliary feed water system, both located in the machine hall,

- implementation of means and procedures to cope with total blackout.

The analysis has taken account of the negative points, but has also included the positive points of the current design of these units. However, positive aspects of the installation cannot contribute to improvement of safety unless the equipment installed is reliable, available and is operated in correct conditions. This is why the consortium has considered that safety system analysis must be accompanied by decisive actions by the utility to improve management, requalification, operation, maintenance and periodic tests of the systems. Consequent improvements in those fields have been required from the utility before restarting.

In the following chapter, we will present some examples of actions taken by the NPP following BNSA/Consortium recommendations.

IV - EXAMPLES OF IMPROVEMENTS ANALYSIS AT THE KOZLODUY UNIT 2 NPP

IV.1 Preventive measures analysis

Hereafter, two examples concerning analysis performed on the implementation of additional preventive measures are presented. They deal with the reactor protection system in one hand, the protection against overpressurisation in the other hand.

IV.1.1 Reactor protection system

As the reactor scram function is essential for the safety of the plant, the following has been considered vital by BNSA/Consortium to be fulfilled :

(i) as a first priority, to demonstrate and to ensure high reliability of the existing reactor protection system (RPS), especially in view of the scram breakers, and mechanical components,

Taking into account the operational feedback on the reliability of, among other things, relays, reactor scram contactors and on the probability of mechanical blockage of the control rods, the need to perform an accidental study on the anticipated transients without scram had to be investigated by the utility.

The NPP has presented two studies on the reactor scram system showing that no single failure of a component of the system can lead to the failure of the system.

This answer did not constitute a satisfactory answer to the Consortium/BNSA request, which required analysis of operational feedback of VVER 440 on the reliability of relays and reactor scram contactors of the system to justify implementation of measures.

In addition, the NPP has presented a generic thermohydraulic study performed on ATWS for VVER. This study concludes in the case of loss of the main feed water that there is no problem of DNBR and no increase of pressure above the design pressure of the primary circuit. The main assumptions of this study are not clearly determined, especially the value of the moderator coefficient. Consequently, the results cannot be approved.

In consequence, the Consortium advises the BNSA to request NPP :

- to provide before start-up a study of the reliability of relays and reactor scram contactors based on the operational feedback of the VVER type,

or

- to justify before start-up the assumptions and the results of the studies performed on transients without scram.

(ii) The NPP should ensure that the scram signal cannot be totally inhibited by manual interlocks or simple operator actions, in particular, to discontinue manual setting of neutron flux level.

About the switches used on a few VVER plants which inhibit fall down of the control rods in the case of reactor scram, the NPP has presented the design of the reactor scram of Kozloduy unit 2 which is different from some others VVER's mentioned and cannot lead to this problem. Furthermore, a study has been performed by ENERGOPROEKT Sofia to verify this fact.

As concerns inhibition of signals of reactor scrams, it is possible and necessary to inhibit, in some states of the reactor, some of them but they are automatically re-activated when this state is left.

An automatic function has been implemented to remove neutron flux measurement systems to the right positions.

The Consortium advises the BNSA to agree on the NPP's position.

(iii) In order to cope with the transients and in view of the outcome of similar studies performed in Western countries, it has been recommended to provide the additional automatic scram signals :

- low level in Steam Generators, (in view of avoiding the emptying of the SGs)
- high pressure in primary circuit,
- high level in the pressuriser (to avoid the operation of the safety valves with water),
- low pressure in primary circuit to take into account the inadvertent opening of one safety valve; this signal should not be correlated with a pressuriser low level signal.

The NPP has presented the additional reactor scrams which will be implemented before start-up of the plant:

- low level in SG,
- low pressure in main feed water header,
- low pressure in primary circuit,
- low level in pressuriser,
- high primary pressure,
- increase of pressure in the containment.

The reactor scram on high level in the pressuriser will not be installed due to a problem in level measuring. Only a signal in case of abnormal increase of level will be sent in the main control room to advice the operator.

Taking account of the fact of installation of high primary pressure reactor scram, of the free volume in the pressuriser and of the possible flow of the make-up pumps, the Consortium advises the BNSA to accept that this additional signal will not be implemented and to require NPP to continue the investigations of the possibilities of installing it in the future.

IV.1.2 Control of the pressure

The reactor cooling system is equipped with a pressuriser connected to the hot leg of one primary loop by two 200 mm connecting pipes in the part which cannot be isolated. The pressuriser spray pipe is connected to the cold leg of the same (unit 1) or the next (unit 2) loop by means of an 100 mm pipe. The pressuriser is equipped with two safety valves discharging into a cooled relief tank protected against overpressure by a bursting membrane. There is a possibility of opening these valves manually. But :

- There will not be before the re-starting of the unit, installation of activation criterion for reactor scram in the case of high water level inside the pressuriser.

- There is no possibility of protecting the primary circuit against overpressure when the primary is at cold temperature during cold shut-down when pressuriser is full of water.

In consequence, the following recommendations were proposed by the Consortium to the BNSA :

(i) To cope with the "pressuriser safety valves stuck open" transient, the criterion for reactor scram should be changed from "low level associated with low pressure in pressuriser" to "low primary pressure" only.

This problem is presented in previous paragraph.

(ii) It is necessary to install a device to prevent overpressure at low temperature, taking into account all the situations which could lead to primary overpressure.

The NPP was required by BNSA to install a device to prevent over-pressurisation at low temperature.

At the beginning, the NPP investigated the possibility of installing an interlock on the safety valve of the pressuriser so as to have automatic protection according to NDTT if these valves can operate with water.

Studies are still in progress and only compensatory measures have been defined.

They are the followings:

- deconnection of Safety Injection (SI) pumps,
- implementation of an alarm at 35 bars correlated with NDTT,
- use of the relief valve of the make-up system.

Furthermore, new temperature measurement devices were installed:

- temperature measurement in the bottom of the vessel but external to vessel (there is no temperature nozzle in the bottom of the vessel),
- new temperature measurement on the pressuriser spray lines.

However, it was not planned to keep a low level in the pressuriser.

The measures which have been presented by the NPP have been judged acceptable. They have been implemented.

The BNSA/Consortium noted a favourable progress in this field, which is generic to all VVER type reactors, and were sensible to the fact that the NPP has become fully aware of its importance.

It remains to be checked, before start-up, whether the temperature in the loop is representative of vessel embrittlement temperature.

(iii) The systems used during cooling down of the plant must be supplied with emergency power to specifically avoid over-pressurisation of the primary circuit in the event of a blackout.

The NPP has confirmed that the pumps used to cool down the primary system with the secondary system full of water are backed-up by the diesel generators. This consequently covers the concern to limit the risk of cold over-pressurisation of the primary circuit.

IV.2 Development of procedures for design basis accident

We limit our presentation to the example of the steam generator tube rupture analysis.

A steam generator tube rupture (SGTR) could lead to a situation where the leaktight compartment system is by-passed, in the case of overfilling of the affected steam generator and of secondary safety valves being actuated. However, one of the positive aspects of the design of this kind of reactor should be taken into account, as they can mitigate the consequences of this accident: the presence of the Main Isolation Valves (MIV). These valves could be used in a valuable way to isolate the affected steam generator, if this steam generator has been previously identified.

Fission product levels are monitored in both the primary and secondary circuits. The measurements in the secondary circuit are used to monitor for damaged steam generator tubes. This is achieved by sampling in the main condenser gas exhaust. Early isolation of steam generators with ruptured tubes is important in terms of maintaining the primary circuit water inventory and avoiding the transfer of large quantities of activity to the secondary circuit. The existing equipment does not identify tube ruptures in specific steam generators and should therefore be supplemented by additional instrumentation on each steam generator outlet.

So it was required:

- To develop a SGTR procedure,
- In such situations, the operator would have the possibility of isolating the affected primary loop using the main isolation valves. An increase in the reliability of these valves is therefore needed.
- To install an activity monitoring device in each steam generator in order to identify the steam generator affected by a tube rupture. Information should be available in the main control room,

During normal operation, possible leakage would be identified. The NPP has confirmed the implementation of technical specifications on primary to secondary side leaks, and the implementation of a procedure to cope with such primary to secondary side leaks (without HPIS actuation).

A SGTR accident study has been made (thermohydraulic calculation), dose calculation is not available.

Specific procedure was developed in which isolation by the MIVs is planned. The NPP presented the study relating to the MIVs. It seems that the values can operate under a maximum pressure drop of 125 bars with a closure time of 78 s. The maximal tolerable temperature at the motors is 102°C. There is also a special device to guarantee the leaktightness of the valves. However, total closure of the valves can only be achieved manually. The radioactivity of room where the operator will operate the valves is monitored. It has to be noted that three of these valves have been replaced and three others have been repaired.

The NPP confirmed that measurements of activity at each SG outlet are given in the main control room. The NPP indicated that there is an activity measurement for each turbine ejector and that gammametric measurement will be installed for each steam generator outlet. They will be used during the SGTR procedure to confirm the affected steam generator.

It has been noted by the Consortium that a major improvement relative to previous situation was obtained. However, proof of safety still not exist (SGTR study not proved conservative (initial power, pressuriser heaters), no dose calculation, making it impossible to check the maximum tolerable activity in primary circuit). Progress are still necessary.

IV.3 Beyond design accident analysis

Two examples are presented hereafter. They concern the treatment of the HPIS header break and the loss of feed water systems.

IV.3.1 Treatment of a break on the HPIS header

Linkage between ECCS (Emergency Core Cooling System) and cleaning and make-up system at the two headers is not satisfactory. To ensure total availability of ECCS and to avoid a large break in the event of rupture of one line before the diaphragm on the ECCS lines, existing manual isolation valves on each injection line had to be replaced by check valves. However, if manual valves are replaced by check valves, the cleaning and make-up system will no longer operate as it uses the injection lines as letdown lines. This is a major safety concern, and, as such, it has been required that a solution must be provided before reactor start-up. In addition, change of the position diaphragms on each injection line had to be studied to fulfil the single failure criterion.

Due to the impossibility for the NPP to implement the design change, it was agreed by BNSA/Consortium that the modification of the ECCS headers would not be implemented during this outage. It is therefore needed to consider that the present design of the system does not allow to cope with a break located on one of the ECCS headers. The six loops connected to the affected header will drain through the break and the flow of the ECCS pumps will also feed the break.

To face this major shortcoming in the design of the ECC system, the NPP has proposed a number of compensatory measures:

1. the headers have to be checked (100 %).
   Full in service inspection was performed, defects were repaired

2. in case of a leak in the primary side (0.2 m3/h < Q < 2.5 m3/h), the NPP would apply a procedure which makes it possible to localise and to isolate the leak. The various operations would be :

   - identify a leak using drain in the confinement,

   - identify the locations,

   - isolate the leak. The header would be isolated using the manual valves of which operating wheels are located outside the hermetic compartment.

For BNSA and the Consortium, due to the existing scheme of the HPIS, it is vital to be able to identify a leak on an injection line from HPIS or on the headers. This compensatory measure before reconstruction was accepted by the NPP during licensing meeting but no realistic measures have yet been taken.

In consequence, the Consortium proposed to the BNSA which agreed the following recommendations :

- the NPP should propose, before start-up, a permanent leakage monitoring system.

- In the case of a break in the header, it is required to write before start-up an emergency procedure using realistic assumptions (faster cooling by secondary side to increase high pressure injection flow may constitute a solution). This cooling, if it is confirmed that it will not enhance vessel integrity, will make it possible to depressurise the primary circuit and thus to obtain a sufficient ECCS flowrate to protect the core. The BRU-A cooling capacity at 53 bars is 2 x 400 t/h and the BRU-K one at 50 bars is 4 x 400t/h.

These points are still open, and will be subject to discussions during the next licensing meetings.

IV.3.2 Emergency feed water system (EFWS)

The emergency feed water system feeds the SGs in the event of failure of the main system. The EFWS consists of two trains and two pumps (2 x 100 %) which are installed in the turbine hall and situated close to the main feed water pumps. Units 1 and 2 are fed only from the two feed water tanks (deaerators) whilst, in units 3 and 4, there is an additional feed from one water storage tank of 500 m3 capacity, located outside the turbine hall. The emergency feed water system is interconnected with the main feed water system. The steam generators have only one nozzle for both feed water systems. The emergency feed water pumps inject this water at the 14.7 m platform into the main feed water pipes of each SG. The pumps start up in the presence of one of the following signals:

- low level in three out of six steam generators,
- loss of off-site power.

The whole emergency feed water system is installed in the turbine hall, without separation from the main feed water system. In case of hazards (fire, flooding or missiles), all main and emergency feed water pumps can fail (common mode failure).

The EFWS and the safety relief valves of the SG participate in decay heat removal. In the event of an accident, in order to cool the primary circuit, it is necessary to use the steam-dump-to-atmosphere valves.

In the event of loss of the main feed water system, operation of the EFWS may be required for a long period, requiring re-supply of the feed water tank. The extension of the reserves of water by the use of an additional feed is important for the safety of the plant. The possibilities of installing a new tank should also be studied.

In the Kozloduy units, safety is currently based on the continuity of the water feed to the steam generators, and the removal of decay heat by steam dump to the atmosphere. The most likely causes of the loss of this function are an earthquake, a fire, or flooding in the turbine hall. Separation or protection of the existing equipment seems to be very difficult to obtain.

Three measures were possible for the maintenance of the function:

1. creating a new EFW circuit outside the turbine hall, and also moving the valves for steam dump to the atmosphere outside the turbine hall,

2. obtaining EFWS redundancy by an other system,

3. seeking an alternative long-term decay heat removal system, when the secondary system is unavailable, by the use of resources (present ECCS in conjunction with pressuriser safety valves) which would allow "feed and bleed" of the primary and the removal of the energy contained in the sealed compartments (by use of the Spray System heat-exchangers cooled by the Service Water System (SWS)). This solution, in particular in the context of an earthquake, would require a review of the ability of the service water system to cope with an earthquake (cooling of the Spray System- (SS)) by backing-up this system electrically and by qualification of the safety-relief valves of the pressuriser for operation with water.

After discussion with the NPP it was required that, before restarting the units, the latter must improve the source of water supply for EFWS, independent from the deaerators, and also make available a "feed and bleed" operating procedure in the control room.

A draft of the procedure was provided. Because of the large amount of water contained in the steam generators and because of the presence of one reactor scram signal on low level in the SGs, which both guarantee decay heat removal for several hours, this procedure would only be used in the long term. Consequently, present performance of ECCS, SS and SWS for this type of operation seems to be acceptable.

Concerning preventive measures, two additional signals related to secondary side have been implemented. These signals lead to turbine trip, reactor scram and actuation of two pumps of the EFW system. The signals are:

- very low level in SG. Each steam generator is equipped with three level transmitters. The signal is generated by actuation of two out of three level transmitters on two steam generators,

- low pressure in the SG feed water header.

It has to be noted that new measurement channels have been implemented.

Concerning improvements of the possibi'"ties to refill steam generators, NPP has presented the various solutions which are now available. They consist in:

1. feeding the steam generators by mobile fire engine pumps (40 bars pressure),

2. feeding the steam generators from the condensate tanks when the pressure is lower than 5 bars. One procedure describing these actions is implemented. One should note that there is no link between this procedure and the "feed and bleed" procedure. The operator could therefore have forgotten to check the steam generator levels, because of the actions in progress; the contingent emptiness of the SG would lead reaching temperature and pressure levels in the primary circuit that would impair the "feed and bleed" effectiveness.

Concerning implementation of procedures, at this stage, the NPP has developed three procedures:

1. filling of SG by mobile fire pumps at high pressure (P =40 bars) using existing water schemes,

2. filling SG by mobile pumps at low pressure (P < 5 bars). Time evaluated to field these facilities is 1:30h,

3. feed and bleed procedure.

The BNSA/Consortium required that a criterion should be defined in these procedures allowing to the operator to apply feed and bleed. The reason is the following: after use of water in the SG, the temperature and pressure in primary will increase due to residual heat. In this case, it is necessary to put into service feed and bleed before reaching a temperature at which saturation pressure is higher than the injection pressure of the high pressure injection pumps, which, even in the case of opening of a pressuriser safety valve, would impair injection by the pumps.

To confirm the possibility of using feed and bleed, it is necessary to determine the capability of the spray system to evacuate decay heat. The note dealing with the spray system analysis concludes that it is necessary in case of a small loca (32 mm), to use two spray pumps so as not to exceed 65°C in the boron tank (maximal tolerable temperature of the spray pumps). In this case, this temperature is reached after 26 minutes considering that decay heat is removed by secondary side. This result has to be confirmed because the assumptions used are not clear. Specially, it is not clear that the use of SWS to remove heat through exchangers SS/SWS is considered available as soon as the spray system starts up. This use constitutes new improvement: previously, the SWS was put into service only when the temperature reached 65°C.

The BNSA/Consortium noted that consequent progress has been performed. However, it is still necessary, before start-up, that the NPP:

- defines a criterion to require immediate application of feed and bleed,

- checks the assumptions used in the mentioned above analysis of the spray system,

- verifies the conclusions of this analysis (necessary use of two SS pumps in case of DBA),

- verifies that the spray system is able to remove decay heat during application of the feed and bleed procedure.

These points are still open and will be discussed during the next licensing meetings.

V. CONCLUSION

Following the work performed by GRS/IPSN on Greifswald units 1-4, by the IAEA on the VVER 440/V 230, and by the Consortium on Kozloduy units 1-2, it is clear that this type of reactors has a lot of major safety deficiencies. Among others are :

- the limited design basis accident to a limited primary break of 32 mm,
- the lack of pressure containment ant its particular design,
- the lack of application of the single failure criterion,
- the lack of protection against common mode failures,
- the poor level of the quality of the instrumentation and control equipments,
- the lack of qualification of the safety equipments,
- the lack of accident procedures.

It is also clear that strict appliance of Western standards would require large scale (and may be non feasible) reconstruction measures.

However, the decision to continue to operate or not this kind of reactors belongs only to local authorities.

The role of the Consortium, as defined by the Commission of the European Communities is to reinforce the Bulgarian Nuclear Safety Authority, to assist them in the implementation of licensing process, and to provide technical recommendations in order to reinforce the safety level of these units. The depth of the required modifications depends on the considered rest life time of the units. To provide its recommendations, the Consortium assumed that operation time was limited to 3-4 years for Kozloduy units 1-2.

Through the implementation of its outage programme, the utility, with the help of WANO, on one side, and the Bulgarian Nuclear Safety Authority on the other one showed their "wishes" to upgrade the safety level of these plants. However, it remains still necessary for the utility to provide some information, to implement some up-grading measures, and tc perform some requalification tests on safety systems. It is important to point out that the positive impression given by the NPP during this one year process hat not be jeopardise by a decision to restart the unit just a few weeks before the full implementation of the outage programme.