7. OTHER TOPICS

7.1 Expert systems

Work is in hand on a number of expert system topics. These include a rule based aid to operating rule compliance.

7.2 Training simulators

As with most instruments, work on training simulators has been a matter of slow improvement, in this case towards greater realism. A general purpose Magnox system now exists at the Nuclear Electric Training School in which a generic desk is complemented by variable back panels which can simulate any of the stations. AGR simulators are increasing their scope and veracity.

The Sizewell B simulator has now been delivered.

8 SUMMARY

As will be appreciated from the above, the last two years have seen considerable progress in the UK despite the interruptions and problems generated by organisational changes. These changes have produced a new sense of urgency and many better insights into the needs of the industry but the future is still unclear and lack of long-term planning causes problems. There seems little doubt, however, that international collaboration will increase and that the industry will come to depend more and more on such collaboration.

Worldwide as well as in the UK, systems are increasing in complexity and sensitivity thereby providing opportunities to operate more economically, closer to plant limits. The thrust is towards higher outputs and improved safety but there is concern that this very complexity could lead to lack of understanding and reverse the trend. Certainly there is a tendency to use complex feedback as a safety claim and as a way of overcoming instrument limits. One has doubts about the wisdom of this course in the long term.

We look forward with interest to 1994.

REFERENCES

1. Goodings, A. "National report on nuclear power plant C&I in the United Kingdom." Proceedings of a technical committee meeting organised by the IAEA. 8-10th May 1989. IAEA. IWG-NPPCI-90/1
2. Smith, I.C and Wall, D.N. "Programmable electronic systems for reactor safety." Atom 395, September 1989

DEVELOPMENT OF MONITORING, CONTROL AND PROTECTION SYSTEMS OF NUCLEAR POWER REACTORS IN THE USSR: STATUS AND TRENDS

V.V. KONDRAT'EV, M.N. MIKHAILOV, V.K. PROZOROV
Research and Development Institute of
Power Engineering

A.G. CHUDIN
USSR Ministry of Nuclear Power and Industry

Moscow, Union of Soviet Socialist Republics

Abstract

In 1989-90 the Supervision Body approved the new safety regulations for nuclear power plants. The operating plants do not always completely satisfy them and a great amount of work to develop operating power units up to the conditions required is necessary.

This paper describes briefly the main changes made in monitoring, control and protection systems of nuclear power reactors to increase the reactor safety.

The following fields are presented in the paper:

- general status of the NPP control and safety systems and instrumentation in USSR,
- sensors,
- electronic equipment,
- actuators improvement,
- qualification tests.

1. INTRODUCTION

The USSR nuclear power should be considered against the background of the quickly changeable economic and political situation in the country.

The USSR nuclear power is based on the two main reactor types: WWER and RBMK which provide for today about 12.3 % of electric power needs in the country.

After the Chernobyl accident the counteraction to the nuclear power was so strong that some power units of NPP under operation were forced to have been closed, the construction of a number of new ones was stopped and conserved.

At present positive changing of the attitude towards the nuclear power is promoted with the reserve power absence in the country power system, increase of prices for fossil fuel

whole range of its change in any moment of the reactor operation;

- guaranteed subcriticality of the shutdown reactor is no

At present positive changing of the attitude towards the nuclear power is promoted with the reserve power absence in the country power system, increase of prices for fossil fuel which has to be mined in more remote regions and from larger deposit depths.

At the same time the safety requirements of the supervision bodies both to the NPP under operation and to those under development are hardened. R & D related to this cost much money which are difficult to be found under economic slump conditions. So, in general, the USSR nuclear power nowadays is under a very grave condition. The fact that since 1989 when two power units were commissioned (the third of Smolenskaja NPP and the fifth of Zaporozhskaja one) no one unit of the nuclear power has been commissioned in the USSR proves it. Although, in spite of the sad situation nowadays we are still optimistic about the future.

2. GENERAL STATE OF THE NPP CONTROL AND SAFETY SYSTEM (CSS) AND INSTRUMENTATION IN THE USSR

After the Chernobyl accident the State Committee of the USSR for Supervision over Work Safety in Nuclear Power Engineering (Supervision body) was drastically re-organized.

In 1989-90 yrs. the Committee approved the NPP new safety regulations including new demands the operating plants do not always completely satisfy to, and a great amount of work to develop operating power units up to the conditions required is necessary. From the new demands as those important for the CSS one can note the following ones:

- non-feasibility of common mode failures;
- resistance to droping of aircraft or rocket (this demand along with the former one envisages the necessity to have two instrumentation suites as minimum which are based on different operation principles and located in different rooms);
- demands to fire-resistance and seismic resistance;
- necessity of monitoring the power level within the whole range of its change in any moment of the reactor operation;
- guaranteed subcriticality of the shutdown reactor is no less than 1 % (actually, it does make the subcriticality monitoring system necessary, including long-term outages);
- availability of no less than two independent scram systems based on different operation principles (for example, rod and liquid systems of the absorber insertion);
- availability of the Auxiliary Shutdown Room.

Nowadays investigations and developments which are financed by Governmental bodies including the C & I issues are performed in the USSR in accordance with the complex programmes developed with taking into account the new safety requirements for each of the main reactor types. Performance of the programmes is controlled by the Ministry of the Nuclear Power and Industry and by Supervision body. Some totals of the performance of the main items of these programmes are stated below.

3. SENSORS

In the sensors area an extensive introduction of new technologies did not occur. The main types of the neutron flux density are current compensated boron ionization chambers with different sensitivity and under startup modes-impulse uranium ionization chambers. To control the distribution of the neutron flux density through the core volume -emission Hf- and Rh-sensors as well as high-temperature incore ionization chambers with uranium coating that are made on the basis of the cables with mineral isolation are employed.

On the basis of the enumerated sensor types a sufficiently wide spectrum of devices different in the structure and sensitivity was developed. It allows to cover practically all the demands of the neutron flux density monitoring from the shutdown reactor to the nominal power level.

In small research reactors where there is little room to mount sensors the wide-range sensors operating under the impulse, fluctuation and current modes are employed. Speaking

As applied to the WWER and RBMK-type reactors the thermometric indicators of the coolant level and complexed coolant-level meters are developed

In small research reactors where there is little room to mount sensors the wide-range sensors operating under the impulse, fluctuation and current modes are employed. Speaking about the sensors one should also mention the development of fire-resistant and corrosion resistant signalling cables intended to transfer the sensor signals to the secondary instrumentation. Usual multicore fire-safe cables for signalling and control have been developed, and they are implemented at the plants step by step.

In the systems of the thermal parameters monitoring traditional temperature sensors-thermocouples and resistance thermometers are used for measurements. The in-core temperature measurements are based on cable-type thermocouples of calibration XA (K). In this case the temperature of the coolant, moderator, metalstructures is monitored.

In the RBMK reactors 3-zone units of temperature monitoring of the graphite stack were replaced completely for 5-zone ones based on the original five-zone cable-type thermocouples developed in the USSR. In these thermocouples with the same cable diameter (6 mm) five operating junctions located at different stack levels with 1-1.5 m spacing are mounted. It allows to economize the fuel component at the expense of the metal amount reduction in the core as well as to reduce the volume of the buried wastes.

In these reactors in the operating control systems the thermometric assemblies located according to core squares are employed. The information on fuel elements temperature is presumed to be submitted to the reactor operator and to be recorded in the "black box".

In the system of the channel-by-channel monitoring of the coolant flow rate of the RBMK-type reactors the tachometric ball flowmeters proved to be good are employed. Their life-time attains nowadays 50 thousand hours.

Nowadays, the monitoring subsystem of the emergency flow rate change in the distributing group headers of the reactor is being developed on these flowmeters basis. Signals of this subsystem will be used in the scram system.

As applied to the WWER and RBMK-type reactors the thermometric indicators of the coolant level and complexed coolant-level meters are developed.

Their use will permit to increase reliability and accuracy of monitoring the coolant-level in the RBMK separator -drums, heat exchangers and WWER pressurizers.

The long-term operation of the thermometric level indicators in different type reactors showed their high reliability.

Nowadays much attention is paid to issues of the metrologic assessment of the WWER and RBMK C & I systems. The complex program of the metrologic assessment of the NPP operation is made up. Methods and hardware of the metrologic licensing and verification of different C & I systems as well as NPP information systems are developed.

4. ELECTRONIC EQUIPMENT

C & I systems of nuclear reactors, especially ones functionning as emergency protection systems, are based, up to now, on the analog integrated circuits and hard integrated logic.

Its worthwhile to notice that nuclear power is more conservative in the sphere of computers application for main processes control on the plants as compared with other branches of industry. The main reason of above is to meet high safety requirements which make the design problems more copmplicated, lead to higher resource consumption, etc.

Moreover, in different countries there is a variety of approaches and requirements to computers and programmable equipment to be used in various NPP's systems. National standards and regulations as well as practical realization of specific systems are effected by that.

In connection with Soviet NPP's it is possible to conventionally single out three stages of system development with using of computers (Fig.1).

In 60s-70s the practical application of the computers on the Soviet NPP's has begun. The first systems were mainly

Stages of system development with using computers

all NPP's. The year of 1973 may be considered as the beginning

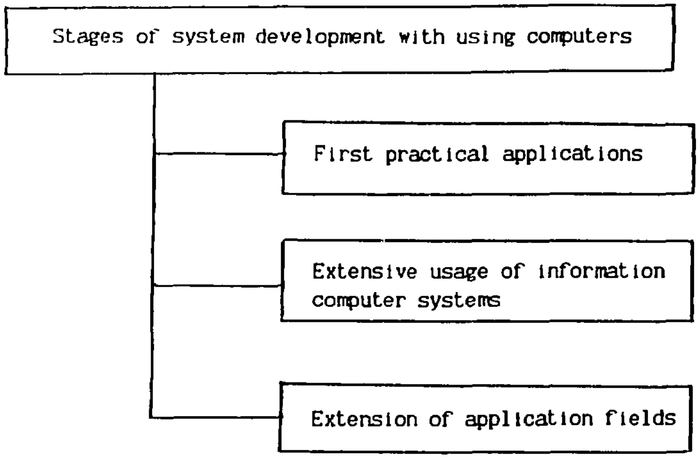


FIG. 1.

carring out analog parameters measurements with following information display on digital indicators. As well, they accomplished the deviation signalling functions and parameters registration on printers.

Up to several hundreds of signals were processed and several tens of parameters were calculated in this case. At the same time control systems as the whole, including the Main Control Room, were designed in such a way that the plant could be controlled at the full power level in case of computer failure.

It was shown that computer application gives the practical effect, namely, it increases convenience of personnel work, reduces the number of instruments, etc.

The second stage is characterized by extensive computer application in structure of information computer systems in all NPP's. The year of 1973 may be considered as the beginning of this stage, when "Skala" - the first centralized monitoring system was introduced.

The "Skala" system was developped for power units with RBMK-1000-type reactor. The further development of hardware and software made it possible to create to the year of 1983 the new generation of information computer systems (ICS), which were introduced on Ignalinskaya NPP with RBMK-1500-type reactors and Zaporozhskaya NPP with WWER-1000-type reactors. The main functions of ICS are the following: gathering, registration, processing and display the information on thechnological process and conditions of various equipment. The third stage of computer-aided systems development is characterized by extension of areas where the programmable means are applicable, including the control and protection functions. Such systems appeared early in 80s. They include REMIKONT system (regulating microcontroller), LOMIKONT system (logic microcontroller) as well as controlling computing suites (CCS) of automatized control system of turbine ACST-750 and its next modification ACST-750R. At present, the industrial manufacturing of control and monitoring microprocessor-based systems (CMMS) has begun.

It should be noted that REMIKONT and LOMIKONT systems are permitted to be only used in the systems of normal operation of NPP, and not in safety systems.

CMMS were licenced by Supervision body. Automatic control systems ACST along with other functions are fulfilling the generator protection. It should be noted that in the automatic control system ACST-750R, in particular, simple enough control algorithms are realized. This system was not designed to realize the control by algorithms, that reguires quite bulky computations.

Nowadays, with some application of programmable means the monitoring, control and protection systems (MCPS) for WWER-1000 and RBMK-type reactors are under development.

It is important, in particular, to point out the following in the MCPS structure of WWER-1000 reactor...

It is important to note some principles which are taken

It is important, in particular, to point out the following in the MCPS structure of WWER-1000 reactor:

- the emergnecy protection system is based on the hard logic which use the scheme "2" out of "3", the limitations forming system (warning protection) is realized on hard logic "2" out of "3" as well; the usage of two of such tripled suites is provided;
- the automatic control is provided to be performed on the tripled computational suite PS-1001, at the same time there is a possibility to manually control the rods by the reactor operator;
- the preliminary processing of the in-core sensors signals, including possible formation of local protection signals, is carried out in the specially designed tripled informational control suite and all calculations of the reactor parameters are realized in the tripled PS-1001 suite.

The monitoring, control and protection system development for RBMK - type reactors goes in step by step way. For example, an instrument producing emergency signal when reducing the operation reactivity margin was developed on the first stage.

It has a read-only memory which transforms the rotation angles of rod position sensors into the codes. It is important to note that the design of this device has got a licence of Supervision body. The development of a logic part of control and protection system on the basis of micro-processors wich is under development now is the next stage of programmable means application. The initial objective of this stage is the function decomposition. This makes it possible with an optimal number of microprocessors to compute complicated algorithms with a sufficient fast-action (about a few tens of milliseconds). This time is characteristic of RBMK-reactor control and protection. At the beginning of the next year we are planning to implement a dummy of a logic part of control and protection system on the basis of microprocessors. Later on a wider application of microprocessors is envisaged in other parts of control and protection system (CPS).

It is important to note some principles which are taken into account within a given development and result from safety requirements:

CPS part connected with fast protection system will be implemented on the basis of traditional "hard logic";

- the development of two sets of protection systems by different producers is envisaged (getting signals from ouf-core ionization chambers and from in-core neutron sensors);
- the redundant equipment is used deliberately
- the physical separation of redundant equipment into different rooms;
- voting (2 out of 3) through all CPS functions is used with actuating signals being voted in each of 223 individual actuator control units;
- self-checking of the system devices including the pulse -coded logics is realized;
- echelon protection is provided;
- proper verification of new systems in test facilities and further stage-by-stage introduction at power units are envisaged.

In the USSR at NPPs with the RBMK-type reactors the "SPRINT" expert system (ES) of the operative diagnostics is commissioned. In the "SPRINT" ES the method of the "failures tree"is realized. The method essence is that object under diagnosis represented as the casual consequent structure reflecting all its considerable functional links. In this case qualitative signs parameters state (more that the norm, less than the norm, within the norm) are treated.

This method is realized successfully to analyze a technical object state with a small parametric dimension.

Nowadays, the "SPRINT" system covering more than 20 technologic systems is under the pilot-industrial operation at the Ignalina NPP Unit 1.

As the computers and their software are developed, constant expansion and deepening of studies of systems of information support of the NPP staff take place. New technologies of the access to information and its treatment

are widely employed. For example, to work with numerous regulations and operational documentation the computer

pressurizer, heat exchanger headers and well cavity of the WWERtype reactor.

are widely employed. For example, to work with numerous regulations and operational documentation the computer hypertext technology realized within the GID instrumental system is employed. The total volume of the documentation covered by this system is approximately 20 thousand pages.

The analysis of tendencies of the control systems development both in the USSR and abroad shows that nowadays the concept to develop integrated systems with a wide use of different software and computers is a dominant one. Such kind of systems should be hierarchical decentralized structures joint by proper networks, mainly, the local ones.

All the abovementioned in the report systems allowing for their further development correspond fully to the approach mentioned and can be considered as integral system components.

Computers application in the systems of safety and those important to safety, giving many priorities, makes designers and supervision bodies face complex and not solved yet in the USSR issues to provide reliability and licencing procedures.

5. ADDITIONAL INSTRUMENTS AND SYSTEMS TO INCREASE SAFETY

The analysis of consequences of different system failures and development of different accident scenarios showed that it's reasonable (sometimes-necessary) to develop and to implement additional systems and devices providing measurement of some-nowadays noncontrollable - parameters and to form accident alarms if these parameters are beyond the allowable limits. They are as follows:

1) Instrumentation for monitoring and emergency alarms formation to reduce the coolant flow rate through the main distributing header and depressurization rate in the primary circuit system of the RBMK-type reactor. This instrumentation allows to identify an accident at an early stage in case of failure of other (now operating) monitoring instrumentation.

2) Instrumentation of monitoring and indication of the steam appearance in certain points of the vessel volume as well as H concentration increase under the cover, in the pressurizer, heat exchanger headers and well cavity of the WWERtype reactor.

3) System of advance automatic notification about seismic waves for the done early reactor shutdown before the seismic wave comes. Necessity of this system is explained by the fact that the main NPP equipment was not subjected in time to the tests which could prove its seismic stability.

4) Necessity to guarantee the shutdown reactor subcriticality no less than 1 % stipulated researches and developments in the sphere of the monitoring systems of the shutdown reactor subcriticality, including those during long-term outages. First of all this system is developed for the WWER-type reactor.

Besides the enumerated aspects much attention is paid to diagnostics of metal condition of the reactor vessels, pipings and heat exchangers. In this connection different systems and instruments of non-destructive control of the metal continuity which are used both in the shutdown and operating reactors and based on the ultrasonic and acoustic-emission methods are developed actively. The system to reveal the coolant small leaks by humidity increase in the primary circuit rooms is also developed. It is of great importance for the RBMK reactor because of a considerable expansion of the primary circuit.

6. ACTUATORS IMPROVEMENT

Mainly, the RBMK reactor designers have to face this problem because the analysis of the Chernobyl tragedy reasons that was performed by the world numerous experts revealed two main drawbacks of the RBMK control rods: small rate and non-monotony of the negative reactivity insertion.

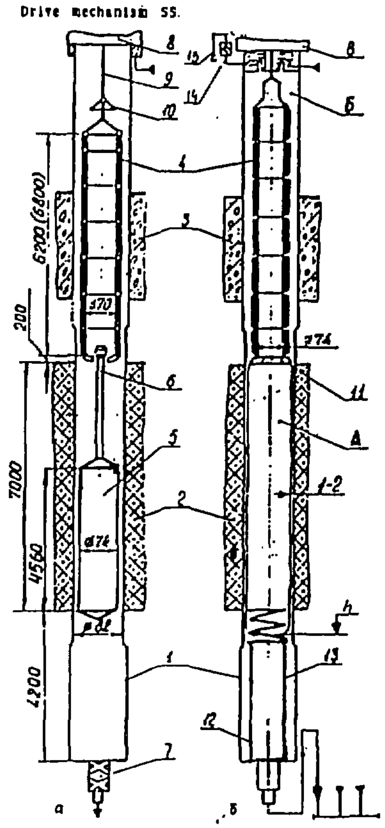
Improvement of the core control rods of the RBMK reactors is made in parallel in several ways.

6.1. First of all, all the reactors of such type are equipped now by the fast scram system (FSS) providing the drop of 21 absorbing rods for 2 s per 6.75 m. This is equivalent to the negative reactivity input 2.4 with average rate 1-1.2 /s.

Reduction of the insertion time of the FSS rods into the core is attained due to the cooling water removal from under the

The rod braking at the end of a free drop is provided by the drive engine switching on into the electrodynamic retardation

Reduction of the insertion time of the FSS rods into the core is attained due to the cooling water removal from under the rod and film cooling of the control rod channel wall (Fig. 2).



а-проектный, с механическим вытеснителем воды; б- БАЗ, с пленочным охлаждением канала;

a - with mechanic displacer
b - with water film cooling (FSS)

FIG. 2. Стержень быстрой аварийной защиты

The rod braking at the end of a free drop is provided by the drive engine switching on into the electrodynamic retardation mode when the rod reaches the insersion depth 6 m.

Nowadays the feasibility to transfer all the CPS rods to the film cooling to reduce the positive reactivity effect under the postulated emergency with loss of water of the absorbing rods cooling circuit is being explored.

6.2. In all RBMK-type reactors the insertion rate of all the rest rods of manual and automatic regulation under emergency situation is also increased due to the late switching on of the electrodynamic braking (after rod sinking down to 3 m). The rate of the negative reactivity introduction of such a system of rods is about 2 /s.

6.3. In order to remove parasite water column in CPS channels, to increase rod's efficiency and subcriticality of shutdown core, all RBMK-type reactors are currently equipped with rods of a new design - ones with onmoving absorbers (Fig. 3). Moreover, to rise their physical capacity the number of rods is increased by 12 pieces.

6.4. A very attractive idea is to rule out from hypothetical accidents the possibility of loss of water from control rods cooling circuit. Thus, an investigation is carried out to develop high temperature noncooling absorber rods.

6.5. To equip RBMK-type reactors with additional protection system that is based on a different operation principle, a new system is developed to insert gas absorber (He) in the core. To date experiments were conducted to define the fast-acting characteristics of conceptual design (time for gas-absorber insertion in the core is no more than 0.8s) and the dependence of this value on various design parameters. The determination of the physical efficiency of the channel with gas absorbers has been carried out on RBMK core physical model. Further directions of investigations were also defined.

СХЕМА РАСПОЛОЖЕНИЯ СТЕРЖНЯ АР,РР,АЗ В КРАЙНИХ ПОЛОЖЕНИЯХ

specifications, including resistance to external effects, such

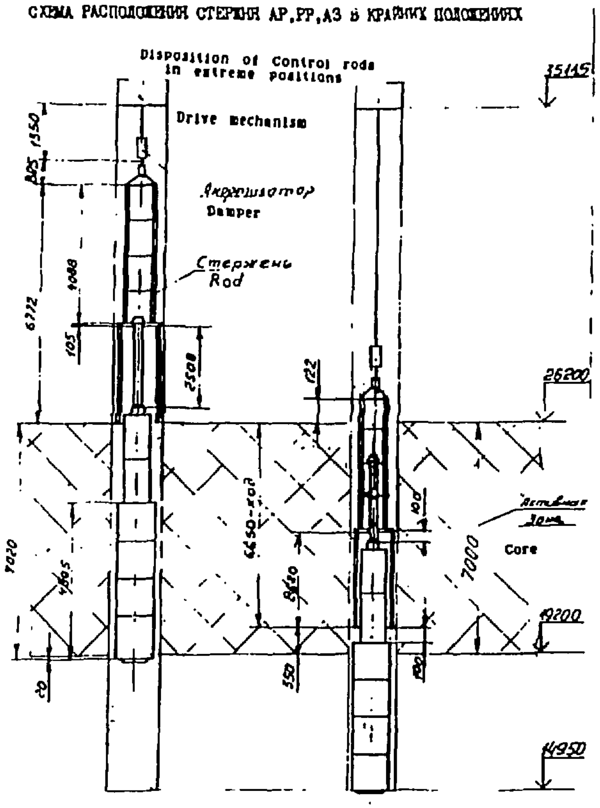


FIG. 3.

7. QUALIFICATION TESTS

All parts of C & I systems are subjected to the versatile qualification tests on the relevant test facilities. Their full compliance with relevant valid standards and

specifications, including resistance to external effects, such as earthquake are checked. These tests are carried out in accordance with methods approved by Supervision bodies, that are directly participating in these works. Approval for industrial manufacturing of the specimens is issued only after all tests are successfully completed.

After the system is being installed at the plant, it is subjected to complex performance and transient interference tests, taking into account the real layout of cabling at the site.

The last type of the test arises certain difficulties, because there are no national, as well as international standard methods and criteria to evaluate test results.

8. CONCLUSIONS

As it has been mentioned above main changes made in monitoring, control and protection systems of nuclear power reactors are connected with enhancement of its safety and their compliance with the new requirements of the supervision bodies. The following fundamental points can be brought out:

8.1. Sensors are developed in the direction of a broader monitoring coverage of almost the whole volume of the core with the aim to obtain a more detailed information on the power density distribution.

8.2. Computer technologies that were initially applied only as computer data systems now stand on the verge of being applied for monitoring and control of the neutron flux density in the core. However, so far microprocessors areapplied in these systems in parallel with the conventional analogue ones and with the "hard logics".

8.3. NPP's programmable computer systems are designed as hierarchical decentralized structures brought together through the relevant local networks.

8.4. A lot of original non-conventional devices for the present generation of nuclear reactors are being now developed for monitoring and forming the emergency signals.

8.5. The necessity for experimental proof of transient

8.5. The necessity for experimental proof of transient interference immunity of control and monitoring systems inevitably leads to the establishment of standards and criteria for such kind of immunity assessment, as well as test methods for their verification. Co-operation with IAEA and other relevant national institutions in this field would be highly desirable and beneficial.

8.6. The upgrading the C & I systems and making them to meet new safety requirements in NPP under operation encounters the problem of additional room for placing the redundant equipment.

8.7. The great importance is attached to the improvement of the control rods design of RBMK-type reactor. The results achieved can be successfully applied to another types of reactors.

REPORT ON NUCLEAR POWER PLANT INSTRUMENTATION AND CONTROL IN GERMANY

W. BASTL
Gesellschaft für Reaktorsicherheit mbH,
Garching, Germany

Abstract

The paper describes the status of the NPP control and instrumentation in Germany. The general technology underlying most aspects of NPP C&I in Germany has not altered since the last progress report although there has been many improvements in detail.

Since the beginning of 1990 the GRS carried out the safety investigations of NPPs in East Germany. The USSR as the vendor of the plants and France were also involved in the project.

The following fields are briefly described:

- status of nuclear power in Germany,
- training simulators,
- backfitting of computers and information systems,
- operator support/new control rooms.

1 Status

At present 19 light water reactors are in operation, with a total electrical capacity of 22 GW. Twelve of them are pressurized water reactors, seven are boiling water reactors. A mean availability of 79,1 % was achieved in 1990, this value increased to 96% in January 1991. Two further PWR's, KWO in Obrigheim (357 MW) and KMK in Mülheim-Kärlich (1300 MW) are shut down by order of the regulatory authorities. It has been also decided, that the fast breeder reactor SNR 300 in Kalkar will not be set into operation.

In east Germany (former GDR) there were 4 nuclear power plants from the first WWER generation (WWER-400/W-230) in operation. Four further plants of the modified type WWER-440/W-213 are under construction. One of these (Greifswald 5) has been in test operation. The progress in construction of the other three plants achieved stages of 30 % to 80 %. Two further plants of the WWER-series (WWER-1000/W-320) achieved about 40 % and 15 % construction progress, they are located in Stendal. All 6 NPP's under construction in east Germany were planed in the 70ies.