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B. BÄRS
P. PELLIONISZ

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Hungarian Academy of Sciences

CENTRAL RESEARCH INSTITUTE FOR PHYSICS

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B. BÄRS* and P. PELLIONISZ

*Technical Research Centre of Finland

Central Research Institute for Physics
H-1525 Budapest 114, P.C.B. 49, Hungary

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ABSTRACT

The paper overviews the general situation of research reactor renewals. As a case study the instrumentation reconstruction of the Finnish 250 kW TRIGA reactor is described, with particular emphasis on the reconstruction of the nuclear control instrumentation. This part of the reactor instrumentation - developed and manufactured by the Central Research Institute for Physics, Budapest - is presented in detail. Besides the presentation of the nuclear instrument family developed primarily for research reactor reconstructions, the quality assurance policy conducted at the manufacturing process is also discussed.

АННОТАЦИЯ

Работа показывает общее положение реконструкции исследовательских ядерных реакторов. Описывается реконструкция измерительных приборов финского реактора типа ТРИГА мощностью 250 кВт, уделяя особое внимание ядерным приборам. Подробно описывается работа, связанная с разработкой и изготовлением новых ядерных приборов в Центральном институте физических исследований в Будапеште. Кроме разработанного в первую очередь для реконструкции исследовательских ядерных реакторов семейства ядерных приборов дается ознакомление с применяемыми способами контроля качества при производстве изделий.

KIVONAT

A közlemény áttekintést ad kutatóreaktorok felujitásának általános helyzetéről. Esettanulmányként ismerteti a finnországi, 250 kW-os TRIGA reaktor müszerrekonstrukcióját, különös tekintettel a nukleáris müszerezésre. A reaktor müszerezésének e részét - amelyet a budapesti Központi Fizikai Kutató Intézet szállitott - a munka részletesen ismerteti. Az elsősorban kutatóreaktorok rekonstrukciójához kifejlesztett nukleáris müszercsalád bemutatása mellett a gyártás során alkalmazott minőségellenőrzési eljárások is ismertetésre kerülnek.

1. INTRODUCTION

Nuclear research reactors were introduced about 35 years ago and at present there are about 400 research reactors all over the world. An interesting feature is that more than 90 per cent of these reactors were built before 1970. In fact, almost 90 per cent of them were built between 1956 and 1967 and are now 15 to 25 years old.

Development in electronics has been rapid during the last 20 years. Although old instrumentation systems may function, some problems will be associated with them in the long run. Old instrument systems are mostly non-modular, which makes it difficult to perform service, maintenance and improvements. They are built of components of old types such as electron tubes or combinations of electron tubes and semiconductors, and are mostly also quite bulky. The increasing problem of obtaining spare parts is also a significant disadvantage. Insufficient reliability, non-modular system and time-consuming service may cause too many, long and undesired interruptions in reactor operation. As time elapses old instrumentation system may also be insufficient concerning safety, especially since there has been a general tendency to impose more stringent safety requirements.

If the instrumentation is reconstructed, say, after 15 to 20 years of use, the benefits of a new instrumentation can probably be exploited during the rest of the reactor lifetime. A significant reconstruction at a later date, for instance 5 to 10 years before the final shut down of the reactor is less justified. Thus the timing of an extensive reconstruction is also important. From these points of view a relatively complete reconstruction of the instrumentation seems reasonable at a large number of the present research reactors.

A case study of reactor instrumentation at the Finnish 250 kW TRIGA reactor is given below, with particular emphasis on the reconstruction of the nuclear control instrumentation.

2. RECONSTRUCTION PHILOSOPHY

How should one proceed at a reactor reconstruction? Though the situation varies from case to case to some extent, it seems to be possible to pinpoint a few features which are common for many old research reactors. Old research reactors are important research, training and service facilities, and their capacity is needed and is expected to be available in the foreseeable future. The mechanical parts of the reactors are mostly in good or reasonable condition and may thus be expected to be usable perhaps for further 15 or 20 years. From this point of view these reactors may roughly be in the middle of their useful age. The reactor building and other lasting parts of the facility represent a significant investment which can be used for decades ahead.

However, a 15 to 25 year old reactor instrumentation can hardly be used for another 20 years without extensive replacements, upgrading or renewal. A partial renewal is not always feasible in the long run, since the mixture of old and new components and parts does not lead to sufficient and lasting improvements. If the instrumentation is renewed, say, after 15 or 20 years of operation, the benefits of the new instrumentation can probably be utilized during the rest of the reactor's lifetime. The cost of completely renewing a research reactor instrumentation amounts to a few per cent of the costs of a new reactor facility. Thus there is also a clear economic incentive to renew only the instrumentation and some other significant parts of the reactor instead of building a complete new facility.

In addition to the cost another disadvantage of an instrumentation renewal is that it interrupts the operation of the reactor for some time. By careful planning and by installing an almost complete parallel new instrumentation, the reactor shut down time can considerably be shortened. For instance at the instrumentation renewal of the Finnish 250 kW TRIGA reactor this time is expected to be a few weeks at the most.

A nuclear research reactor includes several kinds of special equipment for controlling the nuclear fission process and for radiation monitoring and contains conventional instrumentation for the measurement of other process parameters (temperatures, flows, pressures, water quality, etc.). Nuclear control instrumentation comprises several channels for neutron flux or power measurement covering about 10 decades of reactor power.

In a new instrumentation system emphasis should be laid on standardization, flexibility, reliability, service and repair possibilities. A new instrumentation should be based on modern industrial standards with standard modular units, cards, etc. (including electronic testing possibilities, the use of isolation amplifiers with standardized output ranges, etc.). A modern modular system permits to follow the rapid progress in electronics. Experience gained from previous reactor operation can also be utilized at the renewal.

At some research reactors the instrumentation has partly and gradually been modernized by the reactor staff. Such an alternative requires less money for the purchase of new instruments and services but may be rather time-consuming and needs considerable manpower capacity, effort and skill by the staff. Thus even a small reconstruction on the basis of own experience and own resources is unlikely to be feasible. A natural, flexible and relatively inexpensive alternative is to buy special nuclear electronic modules and to let the own staff install them as a partial reconstruction. It is not practical and mostly not even possible to build the special nuclear channels in the reactor laboratory itself, due to the high quality standards and efforts required. A third solution is to renew the whole instrumentation completely, to buy the equipment together with design and installation services from specialized companies. The participation of the staff in the planning and possibly also in the installation process is useful because the instrumentation can then be better tailored to the special requirements of the reactor facility and because such a participation makes the staff familiar with the new system. This third solution will probably require more money for purchasing services, but will most probably give the best and most lasting results as well.

3. THE FINNISH RECONSTRUCTION

3.1 General

The Finnish TRIGA Mark II reactor (FiR 1; 100 kW power, 250 MW pulsing capability and, since 1967, 250 kW steady state power) has been operated for about 20 years. This reactor is thus a typical representative for the large majority of existing research reactors. FiR 1 is the only research reactor in Finland and it is an important research, training and service facility. One of its important functions is the production of radioisotopes for the new isotope laboratory (1976) and for other customers. In addition, the reactor is frequently and regularly used for training purposes. The original reactor control instrumentation delivered by the American supplier General Atomic has partly been renewed, modified and improved, including an extensive modernization in 1974. In addition to the previously mentioned problems, common for many old research reactors, there are also a few other drawbacks in the present FiR 1 instrumentation. Despite an enlargement, the present control console is very crowded. The present cabling might be improved and the risk of fire is estimated to be considerable.

The control console used at present in the reactor hall should be removed to a separate and isolated control room. There is a single high voltage source common for all four neutron detectors without any redundancy. The water activity measurement system in the primary water circuit is insufficient. Many changes have led to a mixed instrumentation. Nevertheless, the failure rate of the present instrumentation is not alarming.

The situation has been evaluated, the above mentioned facts thoroughly considered and a preliminary renewal plan including cost estimates has been elaborated. The conclusion was that a complete renewal of the whole reactor instrumentation should be renewed in 1981. The new reactor instrumentation should be based on modern industrial standard modular units (with electronic testing possibilities, standardized signal ranges (max. 20 mA), isolation amplifiers, etc.). A separate project has been initiated also for the modernization of the radiation protection instrumentation.

3.2 Choice of instrumentation

There are many excellent instrument systems and experienced suppliers on the market. Two principal suppliers have been chosen. This choice was based on the technical and economic evaluation of many quotations and visits to some installations. The new nuclear measurement channels will be delivered by the Central Research Institute for Physics (KFKI, Budapest; Measurement Automation Division) of the Hungarian Academy of Sciences (MTA) and the conventional instrumentation by the Finnish company Valmet Oy Instrument Works.

The standard modular instrumentation offered by KFKI fits well to the TRIGA reactor and only some minor modifications have been made. (Details are given in the next chapter.)

The conventional instrumentation from Valmet Oy has specially been designed for the Finnish TRIGA reactor. Valmet Oy has a significant experience in supplying instrumentation for paper and pulp industry and for power plants.

The choice of the instrumentation involves some contradictions. For instance, the question arises whether it should be based on conventional analog technique or on a slightly more expensive on-line microprocessor technique, with colour TV display, etc. Valmet Oy instrument Works offered both the conventional ELMATIC system and the microprocessor-based DAMATIC system. In the

DAMATIC automation system the signals from the system transducers are transmitted and manipulated by central process stations and traffic control stations. They are applied to a trend memory, and also to a display station with CRT monitors copying unit and line printers. The DAMATIC system includes 4 basic display forms: general display, group display, trend display and alarm display. In addition, a hard copy unit and line printers can be used. The demand signals from the operator to the process are entered by one or more small keyboards and keyboard stations connected to the traffic control and process stations. The automatic power control system, the possible alarm and scram logic, the data links between the reactor and the operator,etc. are included in two or more parallel process stations. In the DAMATIC system - unlike in the conventional ELMATIC system comprising many individual signal channels - all signals are transmitted and manipulated by a centralized processing system. For reason of safety the basic centralized digital data transmission and processing systems have to be duplicated or triplicated or backed up by some analog units. In case of malfunction of a process station, it is automatically replaced by a parallel station.

The DAMATIC microprocessor system could have required some extra efforts and costs. However, if the training and development aspects are overlooked, the microprccessor system seems to possess only small advantages at such a small system as a TRIGA reactor. The extra costs arising from an analog back--up system or a duplication or triplication of the most important display, control and scram functions cannot always be afforded in a small TRIGA laboratory. Since the experience with such microprocessor systems in the monitoring and the direct digital control (DDC) of nuclear reactors is very limited, it is difficult to foresee all aspects, advantages and problems. The system availability may also call for some adaptions, which might increase the uncertainty concerning the result. An inquiry made a few years ago at many TRIGA laboratories revealed very scattered opinions about the necessity and usefulness of such microprocessor-based data collecting and DDC systems for TRIGA reactors.

Since the main goal of the present project was to obtain a reliable and cheap instrumentation in order to minimize shut down time, and because the training and development aspects were considered to be of less importance, instead of the DAMATIC system the conventional analog ELMATIC instrumentation of the Valmet Oy Instrument Works was chosen and ordered for the Finnish TRIGA reactor.

3.3 Significant improvements

From buyer's and user's point of view the new instrumentation includes significant improvements as compared to the old one. The new instrumentation is more complete and includes a number of functions which increase the safety and reliability of the reactor operation, e.g. by improving the scram system. The use of standard modular units, built-in electronic testing equipment, fault indicators, a set of spare units, isolation output amplifiers with standardized output ranges (max 20 mA), etc. make the system flexible, safe, easy to use and to repair.

The instrumentation is housed in standard racks and the system is operated from the 2.5 m long control console. The control console and the instrumentation racks are located in a special new air-conditioned control room. All the main parameters are displayed on meters or on a recorder in the control console. Some channels have parallel meters in the instrument racks, and there are some large reactor power indicators in the reactor hall (log reactor power).

The conventional instrumentation and the lay-out of the control console have been designed specially for the Finnish TRIGA reactor, and were carried out in close cooperation between Valmet's representatives and the reactor staff. Valmet Oy Instrument Works delivered and installed the safety logic system, the automatic control system, the control console and the conventional process measurement channels.

3.4 Time schedule and costs

The preparations for the renewal of the FiR 1 instrumentation were started in 1977 but the renewal has been delayed due to the lack of money. The nuclear channels were ordered from KFKI in September 1980 and the conventional instrumentation from Valmet Oy Instrument Works in January 1981. The installation and commissioning were planned to take place from June to about the middle of August 1981, but have been postponed three months due to delays in rebuilding the new control room and due to the holiday period. In case of unexpected troubles the old instrumentation can be used until the new one works properly.

The cost of the equipment together with the external services amounts to about 250.000 US$ (1 million FIM) excluding the manpower costs of the laboratory staff. About 2 extra person years were allocated to the instrumentation renewal project for the laboratory staff. In addition, the construction of a new control room, including air-conditioning facilities etc. costs about 50.000 US$.

4. NUCLEAR INSTRUMENTATION

4.1 System configuration

In the new nuclear control system of the TRIGA reactor four independent nuclear measuring channels are applied. They will be delivered and installed by the Central Research Institute for Physics of the Hungarian Academy of Sciences (KFKI, Budapest). The nuclear channels will be described in detail in the subsequent sections.

The power ranges covered by the different detectors and channels are shown in *Fig. 1*.

As usual, working ranges are overlapped throughout the whole, 10-decade neutron flux span of the reactor. Each channel contains its own independent power supply, including a high power supply for the detector. The channels deliver voltage and current signals proportional to the measured quantities to the control desk instruments as well as logic signals to the reactor safety logic, as *Fig. 2* shows. Each channel automatically indicates if power or high voltage is failing and if the channel is switched in test mode, thus making the measurement actually impossible. Test signals are provided by special units in order to test availability and accuracy.

The channels give information on the following measured parameters:

- Pulse channel: neutron counting rate from fission detector on logarithmic meter; audio signal characterizing counting rate;
- Logarithmic d.c. channel: ionisation chamber current on logarithmic meter; reactor period value;
- Linear d.c. channel: ionisation chamber current in 15 ranges switched over automatically or manually;
- Safety channel: ionisation chamber current in steady-state or in pulse operation mode.

The safety system generates logic signals alerting the operator or automatically initiating scram if

- the neutron counting rate is too low in the source range,
- the neutron flux is too high or the reactor period value is too slow,
- a channel fault is present.

Channels are supplied with separate outputs for experimental measurements (rod-drop, etc.). To illustrate the modular building block system, the block diagram of one of the channels is shown in *Fig. 3*.

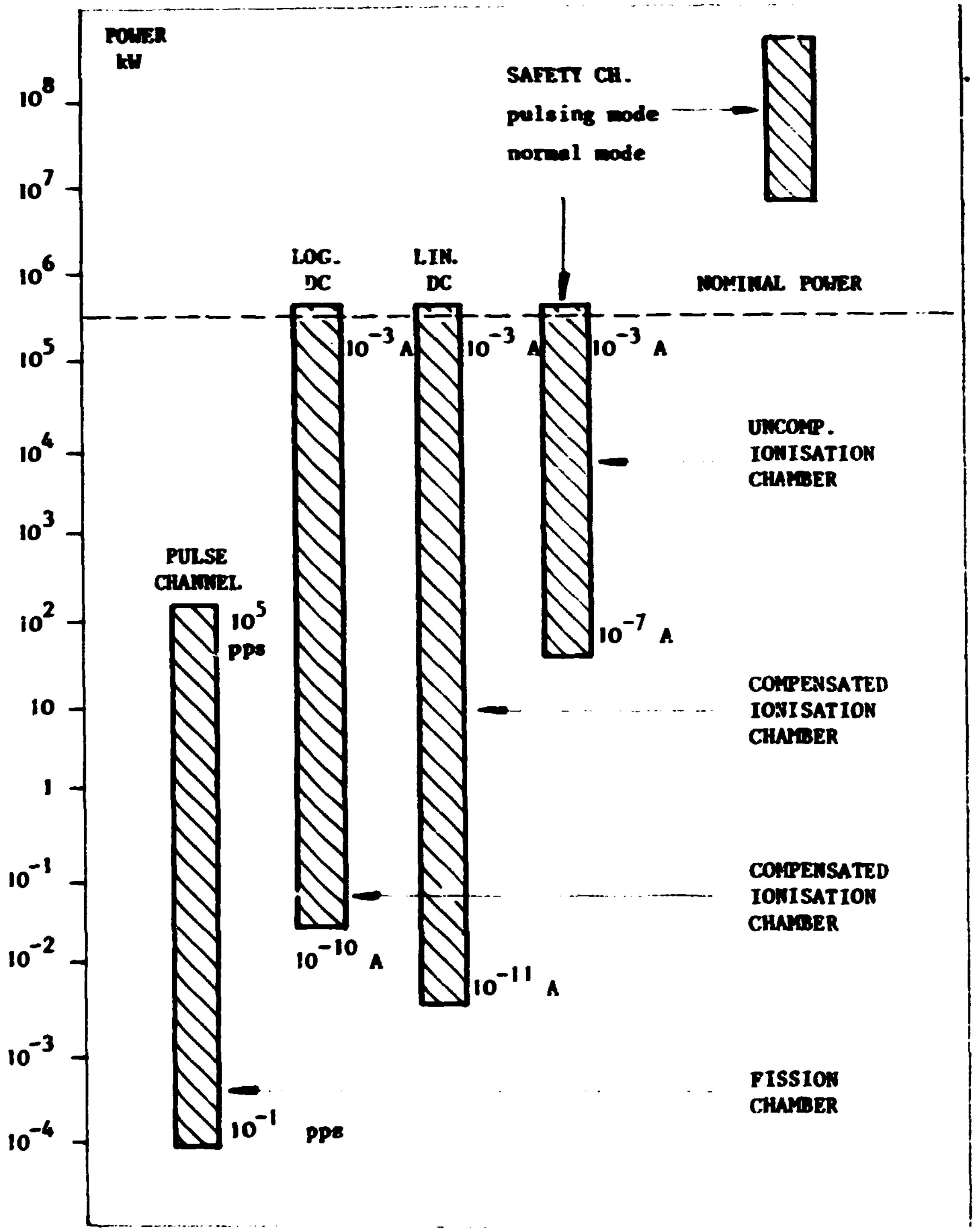


Fig. 1

Power ranges covered by the nuclear channels

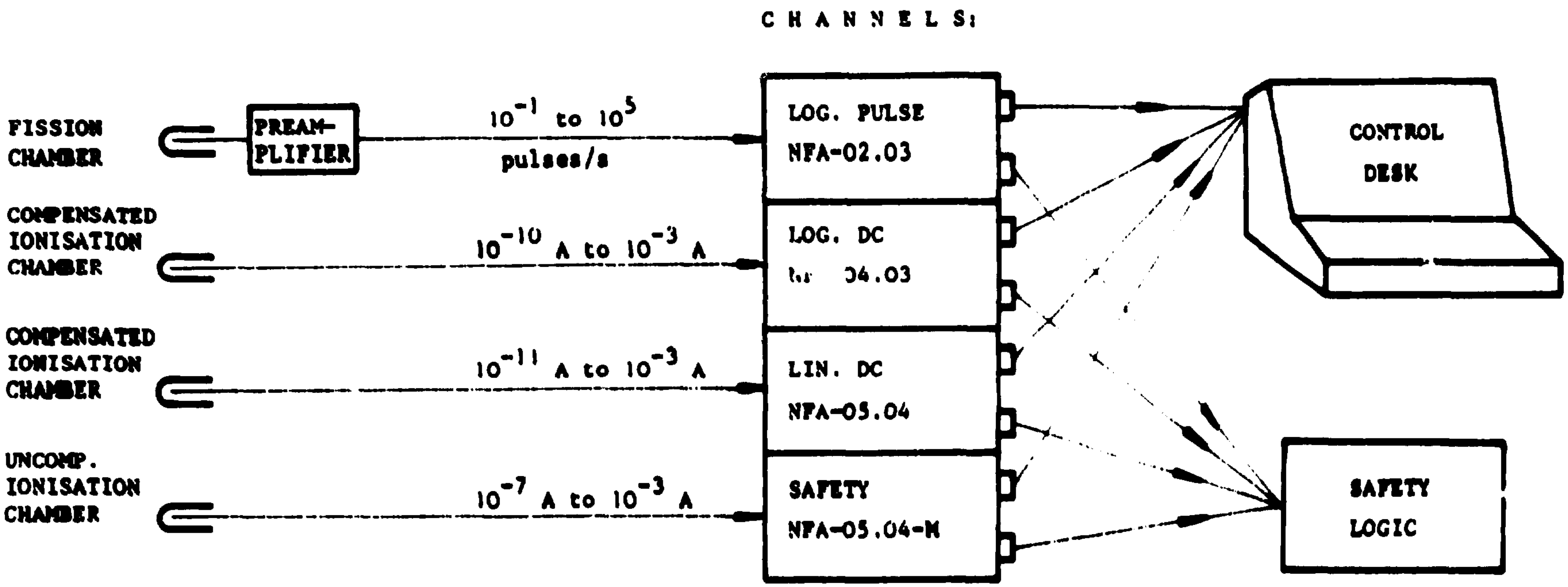
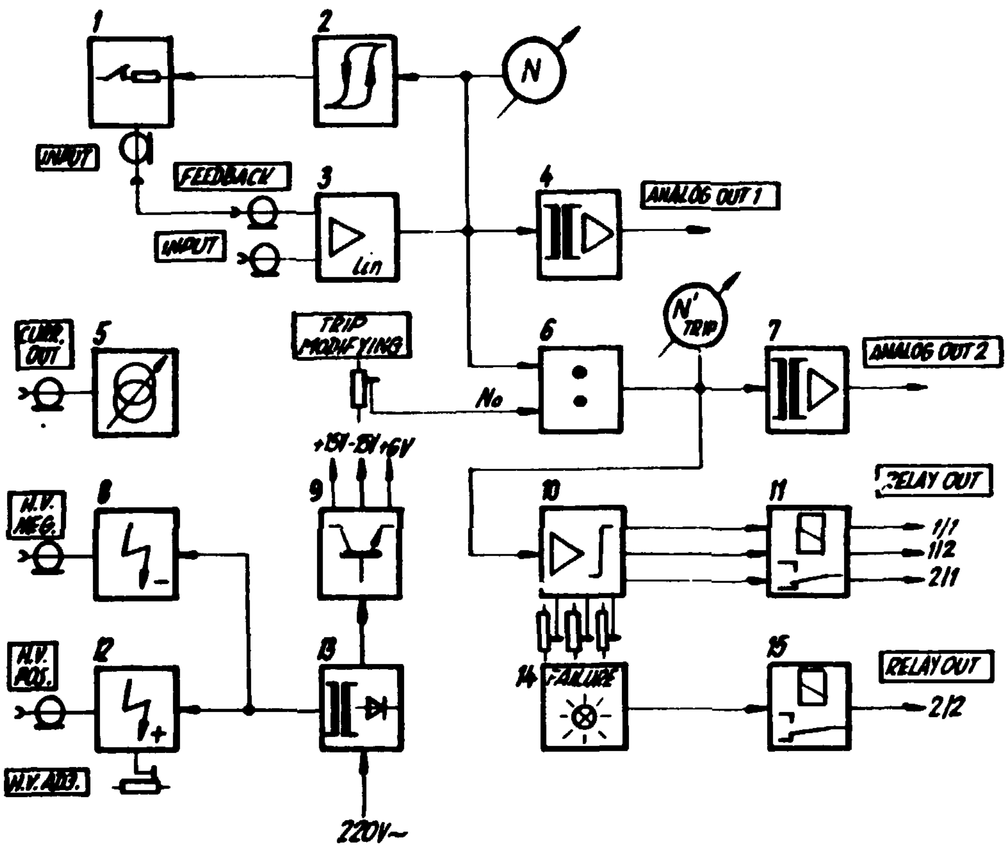


Fig. 1

Block diagram of the nuclear control system



1	Relay controlled feedback system
2	Range controller
3	Linear d.c. amplifier
4 and 7	Twin isolator amplifier
5	Test generator
6	Divider unit
8	1.5 kV high voltage supply
9	Low voltage power supply system
10	Trip system
11 and 15	Relay output system
12	1.5 kV high voltage supply
13	Unregulated power supply
14	Fault monitor system
16	Indicator and controller

Fig. 3
Block diagram of the linear d.c. channel

4.2 System development

The nuclear instrumentation is built up with the modules of the Instrument System for Nuclear Industry developed at the Central Research Institute for Physics, Budapest, during the second half of the seventies [1].

The primary aim of the development was to create an up-to-date and reliable modular instrument system suitable for research reactor modernization - first of all within the institute itself. It was realized, however, that there was also a need for such instrumentation beyond the institute both in Hungary and abroad. Accordingly, during the whole of the development it was kept in mind that the system should be easily applicable at different nuclear installations and it should easily be manufactured when required.

In Hungary, during the last years, the system has been applied at several reactors and critical assemblies. The production licence of the system has been bought by the Hungarian instrument manufacturer GAMMA WORKS. The first installation abroad is the nuclear control system of the Finnish TRIGA reactor. The order was taken in summer 1980 and the complete nuclear system is to be put into operation in October 1981 in Finland. The nuclear instrument system is well fitted to TRIGA reactors and to their special operation conditions highly facilitating both design and manufacturing.

4.3 System features

The instrument system includes all the common functions of the nuclear instrumentation like power supplies, DC and pulse amplifiers, discriminators, counting rate meters, alarm and trip units, different test, check and fault monitors. The system has a modular character. The modules are available in two versions: laboratory modules for individual or small system have front panel organs, industry modules for large assemblies are remotely operated. The plug--in building block system is based on printed circuit boards of 100 × 160 mm Euro-format. The standard 19" rack mounting permits customized mechanical construction, relatively inexpensive design, easy access, and small dimensions. *Figure 4* shows a photo of some modules.

The general characteristics of the system can be summarized as follows:

- modular construction, 100 × 160 mm Eurocard standard,
- acceptance of IEC recommendations,
- high reliability, availability and safety,
- pulse and current measuring channels,
- analog signal at

  voltage source outputs: 0 to +10 V

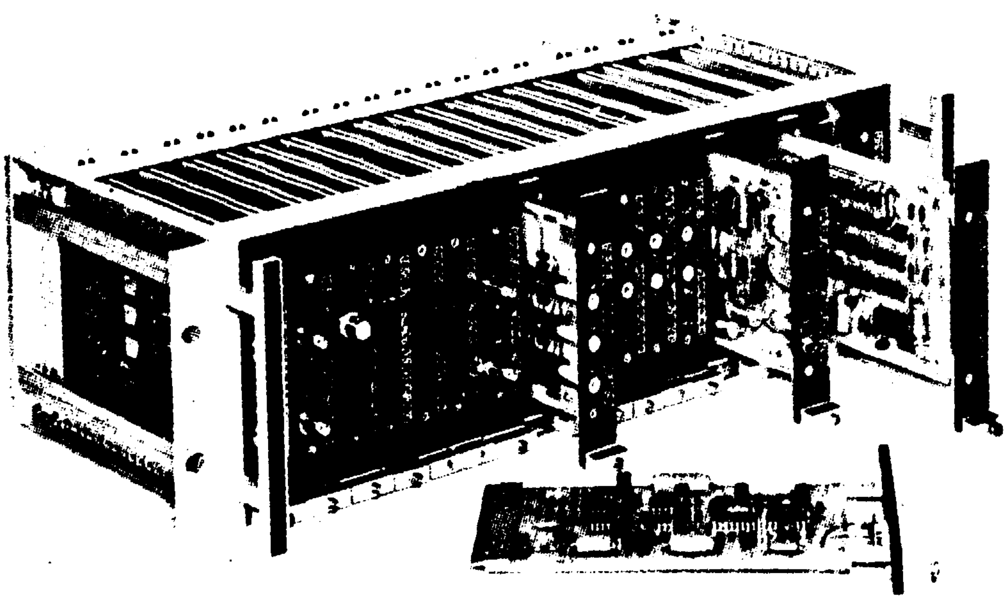


Fig. 4
Modules of the Instrument System for Nuclear Industry

current source outputs: 0 to 10 mA (0 to 20 mA)

- digital signals: TTL

With the system modules a number of standard measuring channels are built together:

- Lin-log pulse channels: neutron flux and period measurements in the source range,
- Lin-log d.c. channels: neutron flux and period measurements in the range from 10^{-11} to 10^{-3} A,
- Water and gas monitoring: gamma monitoring in pulse and d.c. mode,
- Multichannel radiation monitors: linear and logarithmic indication of radioactivity level,
- Analog reactivity meter: operating from ionisation chambers in the range from 10 c/ to 20 $.

4.4 Quality assurance and reliability

Throughout the whole nuclear system design and production, particular consideration was given to reliability. Some of the most important points are the following:

- At the construction of the system, the classical rules of circuit reliability design were strictly followed, e.g. derating, built-in redundancy, minimized stress.
- Fault monitor units are applied which operate on the principle of dynamic logics [2] and automatically signalize irregular voltage.
- Careful manufacturing, high level quality assurance, component and equipment ageing serve for eliminating early failure effects.
- Mean-time-between-failures data are calculated.

The quality assurance procedure followed during the manufacturing is based on consecutive steps of thermal ageing and verifications.

The first step of quality assurance procedures is the testing of the components to be built in at the manufacturer. All electronic components are subjected to thorough visual survey and a subsequent thermal ageing (500 hours at 70 °C). After this process, the most important parameters (leakage current at semiconductors, electrolytic capacitors, current gain at transistors, etc.) are measured and components with dissimilar values are rejected.

During the manufacturing process of the nuclear system for the Finnish reactor, several thousands of components were aged and measured. For instance, the total number of the tested (and the number of the rejected) components was

1527 (151) for diodes, 569 (25) for ICs, 4614 (24) for resistors, 2173 (150) for capacitors, etc.

In the second quality assurance step, complete cards containing all components are measured and calibrated according to their specifications and are subjected to thermal shocks first at 0 °C and subsequently at +55 °C, in accordance with IEC publication 65-2-14, 1974. After testing the normal operation, another ageing process follows (16 hours at +55 °C). At the manufacturing for Finland, several hundreds of data were measured and recorded during the ageing process.

As a final checking, complete nuclear measurement channels are tested under extreme operational conditions during normal functioning (16 hours at 50 °C and 16 hours at 5 °C). During these tests, the output parameters are recorded as documents of the institute's quality control. For the quality control documentation of the nuclear system to the Finnish TRIGA, records of 72 hours were taken and sent to the buyer.

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Kiadja a Központi Fizikai Kutató Intézet
Felelős kiadó: Gyimesi Zoltán
Szakmai lektor: Pallagi Dezső
Nyelvi lektor: Meskóné Kontsag Judit
Gépelte: Polgár Julianna
Példányszám: 310 Törzsszám: 81-563
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