INSTRUMENTATION RENEWAL AT THE FiR 1 RESEARCH REACTOR IN FINLAND

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ABSTRACT

THE FINNISH TRIGA MARK II REACTOR (FIR 1 100 KW, LATER 250 KW STEADY STATE POWER AND PULSING CAPABILITY UP TO 250 MW) HAS BEEN IN OPERATION FOR 20 YEARS. THE REACTOR IS THE ONLY RESEARCH REACTOR IN FINLAND AND IS AN IMPORTANT RESEARCH TRAINING AND SERVICE FACILITY, WHICH OBVIOUSLY WILL BE OPERATED FOR 10...20 YEARS AHEAD. THE MECHANICAL PARTS OF THE REACTOR ARE IN GOOD SHAPE. SOME MINOR MODIFICATIONS HAVE PREVIOUSLY BEEN MADE IN THE INSTRUMENTATION. HOWEVER, THE ORIGINAL INSTRUMENTATION COULD HARDLY HAVE BEEN USED FOR 10...20 YEARS AHEAD WITHOUT EXTENSIVE MODIFICATIONS AND MODERNIZATION.

AFTER A CAREFUL EVALUATION AND PLANNING PROCESS THE WHOLE REACTOR INSTRUMENTATION WAS RENEWED IN 1981 AT A COST OF ABOUT 400 000 DOLLAR.

THE RENEWAL WAS CARRIED OUT IN COOPERATION WITH THE CENTRAL RESEARCH INSTITUTE FOR PHYSICS (KFKI) AT THE HUNGARIAN ACADEMY OF SCIENCES, WHICH DELIVERED THE NUCLEAR PART OF THE INSTRUMENTATION AND WITH THE FINNISH COMPANY VALMET OY INSTRUMENT WORKS, WHICH DELIVERED THE CONVENTIONAL INSTRUMENTATION, INCLUDING THE AUTOMATIC POWER CONTROL SYSTEM AND THE CONTROL CONSOLE.

THE INSTRUMENTATION, WHICH IS LOCATED IN A NEW ISOLATED CONTROL ROOM IS BASED ON MODERN INDUSTRIAL STANDARD MODULAR UNITS WITH STANDARDIZED SIGNAL RANGES, ELECTRONIC TESTING POSSIBILITIES, GALVANICALLY ISOLATED OUTPUTS ETC.

THE INSTRUMENT RENEWAL PROJECT WAS BROUGHT SUCCESSFULLY TO COMPLETION IN NOVEMBER 1981 AFTER ONLY ABOUT 10 WORKING DAYS OF SHUT DOWN TIME. THE REACTOR IS NOW IN ROUTINE OPERATION AND THE EXPERIENCES GAINED FROM THE NEW INSTRUMENTATION ARE EXCELLENT.

1 INTRODUCTION

The Finnish TRIGA Mark II reactor (FiR 1, 100 kW, later 250 kW steady state power and pulsing capability up to 250 MW) has been in operation for 20 years. FiR 1 is the only research reactor in Finland and is an important service, training and research facility. It is obvious that it will remain so also in the future and therefore it is necessary to ensure a high reliability and availability of the reactor operation for a long time ahead.

The mechanical parts of the reactor are in relatively good shape. Some modifications and modernizations had earlier been made in the instrumentation. However, it was estimated that this instrumentation could not have been used for the rest of the expected life of the reactor (15...20 years ahead).

The renewal or upgrading was justified because

- there were increasing problems to obtain spare parts
- it was necessary to replace some old types of components, especially the electron tubes
- the previous system was non-modular
- the wiring and cables were unsatisfactory with risks of fires
- there was no redundancy for some important parts (e.g. the HV supplies)
- the primary water activity measurement system was insufficient
- the old and small extra control panels should be renewed etc.

The justification and basic philosophy for the instrumentation renewal was presented more in detail at the Sixth European Conference of TRIGA Users 1980 /1/ and in a previous report /2/.

After a careful evaluation and planning process the whole reactor instrumentation was successfully renewed in 1981, based on equipment from two main suppliers. The control console was also removed from the reactor hall into a separate control room.

A two-person project group and partly also other personnel at the Reactor Laboratory participated in the project. The technical development that has taken place during the last 25 years was utilized in planning and installing a new instrumentation, which corresponds to modern industrial standards, with high availability and easy service operations.

The new analog instrumentation is based on modern industrial standards with flexible and reliable modular units, standardized signal levels, isolation amplifiers, electronic testing possibilities, self-checking features etc. The modular structure also makes it easier than before to carry out possible changes that may be attractive in the future due to the rapid development in electronics.

2 CHOICE OF INSTRUMENTATION

There are many excellent instrument systems and experienced instrument suppliers on the market. The final choice of the two main external suppliers was based upon technical and economic evaluations of several quotations and upon visits to some installations. The Reactor Laboratory at the Technical Research Centre was also a supplier of basic services in the instrument renewal project.

The four nuclear channels were delivered and installed by the Central Research Institute for Physics (KFKI, Budapest, Measurement Automation Division) at the Hungarian Academy of Sciences. The standard nuclear instrumentation (modules in the series NFI-) from KFKI /2, 3/ was well suited for the TRIGA reactor and only some minor modifications had to be made. The number of nuclear channels is the same as in the old system but the ranges have been partly extended. There is also a possibility for pulsing mode operation and pulse registration (up to 300 MW peak power).

Valmet Oy Instrument Works, who delivered the conventional (the ELMATIC system) instrumentation /4/, indlucing the control console and the automatic power control system has significant experience in supplying instrumentation for process, paper and pulp industry. The installed system is mainly based on the company's standard system ELMATIC, which is an analog instrumentation system that has been in production for several years and has proved very successful and reliable. The ELMATIC system was now used for the first time also in nuclear research reactor instrumentation and with great success.

Valmet Instrument Works also offered their new distributed on-line microprocessor system DAMATIC with colour TV display, a small push-button control board etc. /5/. The authorities were also willing to accept such a DAMATIC system as a basic solution for the new instrumentation.

In the DAMATIC system - unlike in the conventional ELMATIC system comprising many individual signal channels - all signals are transmitted and manipulated by centralized processing units. For safety reasons the data transmission, processing and display systems (including the important and relatively expensive video generator) need redundancy and must therefore be duplicated, triplicated or backed up by some analog units. In case of malfunction of a process station, it is automatically replaced by a parallel station. Such necessary parallel systems will increase the costs. It also seemed difficult to definitely prove the logic function of a safety system based on programmed microprocessors i.e. to achieve an operation without non-allowed loop-holes. So at least a part of the safety system called for some analog back-up. On the other hand, the excellent safety features of the TRIGA reactor make it very suitable for modern instrument systems of this kind.

The conclusion was that the DAMATIC system also is a realistic and an acceptable option. However, the analog ELMATIC system was chosen primarily for the following reasons.

The main goals of the present project were to obtain a reliable and modern instrumentation at moderate costs and to minimize the shut-down time during installation. The training and development aspects were considered to be of less importance. Since the experience with microprocessor systems in the monitoring and control of nuclear reactors is very limited, it is difficult to foresee all aspects, advantages and problems.

The microprocessor-based DAMATIC system is more suitable for much bigger processes where its advantages can be better utilized than in a small TRIGA reactor. The extra costs (in the DAMATIC option) arising from an analog back-up system or duplication of the most important display, control and trip functions are also relatively high in a small system like a TRIGA reactor. An inquiry made a few years ago to many TRIGA laboratories revealed very scattered opinions about the use of computer-based instrumentation for TRIGA reactors.

Valmet Oy Instrument Works analog ELMATIC system was thus chosen, ordered and installed at the Finnish TRIGA reactor. The electronic parts for the primary water activity measurement system were delivered by Alnor Oy (Turku, Finland), while the system was installed and tested by the personnel of the Reactor Laboratory.

3 MAIN FEATURES OF THE NEW INSTRUMENTATION

The new instrumentation contains basically similar types of measurements, controls and displays as the old instrumentation from GA, but some additions and improvements have been made. Block diagrams of the measurement channels are displayed in figures 1 and 2. The old neutron flux chambers were retained and connected to the four nuclear channels.

I The start-up channel operates with a fission chamber in the count rate mode from 10^{-4} to 100 W with a logarithmic display ($0,\ldots 10^{5}$ cps) and with the possibility of an audio signal as well.

II The logarithmic DC channel operates with a compensated (BF_3) ionization chamber in the range $0.1\ldots 10^{6}$ W with a single log. scale and provides the signal also to the period meter (-30 s...∞...3 s).

III The linear DC channel with a compensated (BF_3) ionization chamber has 15 ranges from 0.03 to $3\cdot 10^{5}$ W including manual and automatic range switch. The signal is also used for automatic control.

IV The safety channel is operated with an uncompensated (BF_3) ionization chamber in the range 1...300 kW (I < 1 μA). The same chamber is also used to detect the power pulses (I ≤ 1 mA), with a 1000 times reduction of the amplifier gain.

A more detailed description of the nuclear channes is given in a previous report /2/ and in catalogues /3/ from KFKI.

The new nuclear channels incorporate significant improvements with increased redundancy, safety and reliability. Deviations (± 10 %) in the supply voltages, in the high voltages, in the outputs of the current and period amplifiers in the nuclear channels and failures of the dynamic safety logic (20 kHz checking signal) cause scram and alarm or alternatively only alarm.

According to the supplier /6/ particular consideration was given to reliability throughout the whole nuclear system design and production. The experiences so far verify the fulfilment of these incentives.

The minimum period has been reduced from 7 s to 3 s. Trip signals are obtained from the linear channel (110 %), from the period signal (≈ 3 s), and from the safety channel (115 %). At low signal levels (< 1 cps) in the start up channel the control rods are locked.

Electronic signal generators and display meters for testing purposes and fault indication are included in all nuclear channels. The calibration, scram and alarm functions can be checked quickly and conveniently.

Similarly, the modular signal manipulating and power control system from Valmet Oy Instrument Works includes additional scram and alarm actuators. E.g. malfunctions in the power supplies for essential units will bring about shut-down of the reactor.

In addition to the improvements mentioned previously the following new features may also be of interest:

- Two fuel temperature meters with scram (previously one) were installed. Due to the use of strong Cd shields for the activation capsules in the irradiation ring the neutron sensitive chambers are sometimes in a locally reduced flux and provide too low power estimates. The control of the in-core fuel temperature is thus a more reliable and safer power estimate than the ionization chamber currents.

- A meter for the cooling power (flow rate times temperature difference in the outlet and inlet cooling tubes) was installed.

- A new on-line pH meter for the reactor tank water was installed.

- Two new water conductivity sensors (replacing previous indirect meters in tank inlet and outlet) for direct display of the primary water conductivity at the control console were installed. It was concluded that the water chemistry surveillance should be emphasized in the future because of the relatively old aluminium parts and the fuel cladding of the reactor and in order to prevent undue corrosion.

- Scram from reduced water level (-1 m) in the reactor tank and an additional remote display water level meter were added. The very unlikely possibility of a loss-of-coolant accident has to be taken into account.

- A more sophisticated system for the pulse mode operation was installed:
  a) Pulsing is prevented if the log. power exceeds 1 kW
  b) A trip signal is obtained if the reactor is too long (a few minutes) in the prepulse state (with only one neutron chamber in operation)
  c) Most of the safety circuits associated with pulsing are duplicated. The previous features are also retained including the automatic pulse rod scram 2 s after pulsing.

- A new activity measurement system for the primary water was installed including a NaI(Tl) scintillation detector in an off-tank water container with circulating water from the reactor tank. The signal is connected to a multichannel pulse height analyzer and also to an adjustable single channel pulse height selector and further to a count rate meter with an adjustable alarm level. A Ge(Li) semiconductor detector with still better energy resolution at the gamma detection would be very useful but represents a great investment in such a small instrumentation system. On the other hand, the prompt and reliable detection of possible fission products in the tank water indicating cladding or fuel failures, improper water cleaning etc. is important. GM-based aerosol and gas monitors for the air at the top of the reactor tank are also used for these purposes. The previous GM-tube system for primary water activity measurements was found to be insufficient due to the high ^{24}Na background (from ^{27}Al(n,α)^{24}Na reaction) and since it measures the integral gamma activity with no energy resolution.

- The minimum period at manual operation is 3 s (previously 7 s).

- In addition to the regulating rod ($\Delta\rho/\beta = 0.9$), which is used for automatic power control, the Shim 2 control rod ($\Delta\rho/\beta = 2.3$) can also be used for automatic and slow reactivity compensation during longer periods of reactor operation when the regulating rod is below 20 % or above 80 % of its range.

- The dropping times of the 3 motor driven control rods can be quickly measured by an installed new electronic meter.

- An automatic scale change mode for the linear channel is included.

The nuclear channels, the signal manipulating equipment, the safety system relays, power supplies etc. are located in separate racks in the control room and are connected to the control console. The control console panel houses a two-pen recorder (lin. and log. pwr), display meters, push buttons for command signals, lamps indicating scrams (red), alarms (orange), operation modes (green), state indication (yellow) of various equipment or quantities, some remote calibration potentiometers etc. The lay-out was planned in the Reactor Laboratory.

Figure 3 is a picture of the control room with control console in the front and figure 4 a picture of the control console panel.

The ELMATIC step control system and the associated functional equipment provide a large variety of possibilities, which, however, could not be investigated in detail and fully utilized due to the limited time. The safety requirements and the planning goal to reduce the period to 6 s (previously 30 and 60 s) at the period locked automatic start-up led to contradictions, which could not and cannot be completely solved at the planning and adjustment of the automatic power control system. The alternative of complete automatic start-up based on some algorithm was abandoned owing to negligible benefits and based on effort-benefit considerations. Since there seem to be small or no benefits from a half-automatic start-up as compared to a manual start-up with an automatic scale change, the manual start-up has so far been preferred by the operators.

4 INSTALLATION, TESTS AND COMMISSIONING

The nuclear channels were ordered in September 1980 with a delivery time of 10 months whereas the conventional part was ordered in January 1981. The new instrumentation is installed in a new separate and air conditioned control room. The previous control console was located in the reactor hall. Due to delay in the construction works of the new control room the installations were started in the beginning of October 1981.

The delivery and installation of the nuclear instrumentation from KFKI was accepted on Oct. 23, 1981. The delivery and installation of the conventional instrumentation from Valmet Oy Instrument Works was accepted on Dec. 1, 1981. The instrument suppliers have also supplied an excellent documentation. A relatively complete set of spare parts has been acquired by the Reactor Laboratory.

Since the components and instrument modules had been pretested at the factories by the suppliers, and the conventional part had been assemblied to a great extent at the factory and moreover, because a detailed plan had been prepared, the installation and tests at the Reactor Laboratory proceeded smoothly and quickly. E.g. the control rod drive system was tested in advance with a spare rod assembly. Due to the new separate control room the new instrumentation could be installed almost completely in parallel with the old system and carefully pretested. The installations and pretests of individual measuring channels, command functions etc. were thoroughly planned and carried out. The switch over to the new system (on Nov. 4, 1981) was therefore very swift and straightforward and the new instrumentation worked properly from the very beginning. The old reactor instrumentation was still available and could have been used after a few hours' switch-over. The final tests and calibrations of the new instrumentation at the beginning of November 1981 were thoroughly documented and the results were also delivered to the safety authorities, which had accepted in advance the detailed installation and test program. A new safety report was also prepared. Some additional tests and calibrations of the primary water activity measurement system were carried out later.

The new instrumentation was inspected by the authorities on Dec. 4, 1981 and was accepted. Throughout the planning and installation process a close contact was kept up with the authorities, which were well informed and prepared for the final commissioning of the new instrumentation.

The total shut-down time of the reactor caused by the instrumentation renewal was only about 10 days.

5 EXPERIENCES AND CONCLUSIONS

The new instrumentation has been in routine use since the beginning of November 1981 and with excellent experiences. The stand-by old instrumentation system and control console were never needed again and were disconnected and removed in June 1982.

During the switch-over, test and first month of operation with the new instrumentation a careful supervision and a detailed documentation of the operation were carried out.

A few minor malfunctions of some parts in the instrumentation have occurred a couple of times during abnormal external conditions (breakdown of the compressor in the airconditioning system leading to high control room temperatures in the summer time or exceptionally high humidity in the air). By changing a zener diode in the automatic range controller the previous temporary malfunction (oscillations in the range control at extremely high temperatures) disappeared. By disconnecting an unused extra input from the linear channel current amplifier the previous zero line shifting arising from exceptionlly high humidity (> 85 %) also disappeared. During the first 10 month period of operation we experienced altogether four component failures (one electrolytical capacitor, one operational amplifier, one reed relay and one Valmet display meter).

The instrumentation renewal project, including evaluation of the old instrumentation, preliminary bids for quotations, preplanning, cost estimation etc. started in 1978, but the project was interrupted and delayed due to the lack of funding and was started again in 1980 this leading to some overlapping work. The total manpower supplied by the Reactor Laboratory was about 5 man years, which also included the preparation of a new safety report, planning, partly fabrication, installation and testing of the primary water activity monitoring system, detailed planning of the control console etc. The total cost of the instrumentation renewal project amounts to about $ 400.000 including the new control room, salaries, social security costs etc. In 1981 two persons in the Reactor Laboratory were occupied almost full time with the project with some additional contributions from the operations division.

The frequent contacts between the suppliers and the buyer/user throughout the project were also very useful to the end of influencing the system design and of getting the user acquainted with the new system. The geographical closeness of the suppliers is very valuable in this respect. One representative (Dr. Attila Baranyai) of the Hungarian supplier visited Finland for one year as an exchange research fellow and could also be quickly consulted during the latter part of the project.

As a summary it can be stated that the instrumentation renewal project at the 20 years old Finnish TRIGA Mark II reactor is successfully brought to a conclusion. The new instrumentation, which was completed at reasonable costs is reliable, flexible and can obviously be used for 10...20 years ahead. The formation of a special two-person project group working full time, the detailed planning of all the stages, the utilization of experienced instrument suppliers with standard and well tested equipment and the close contact with these suppliers and the authorities contributed to the successful result.

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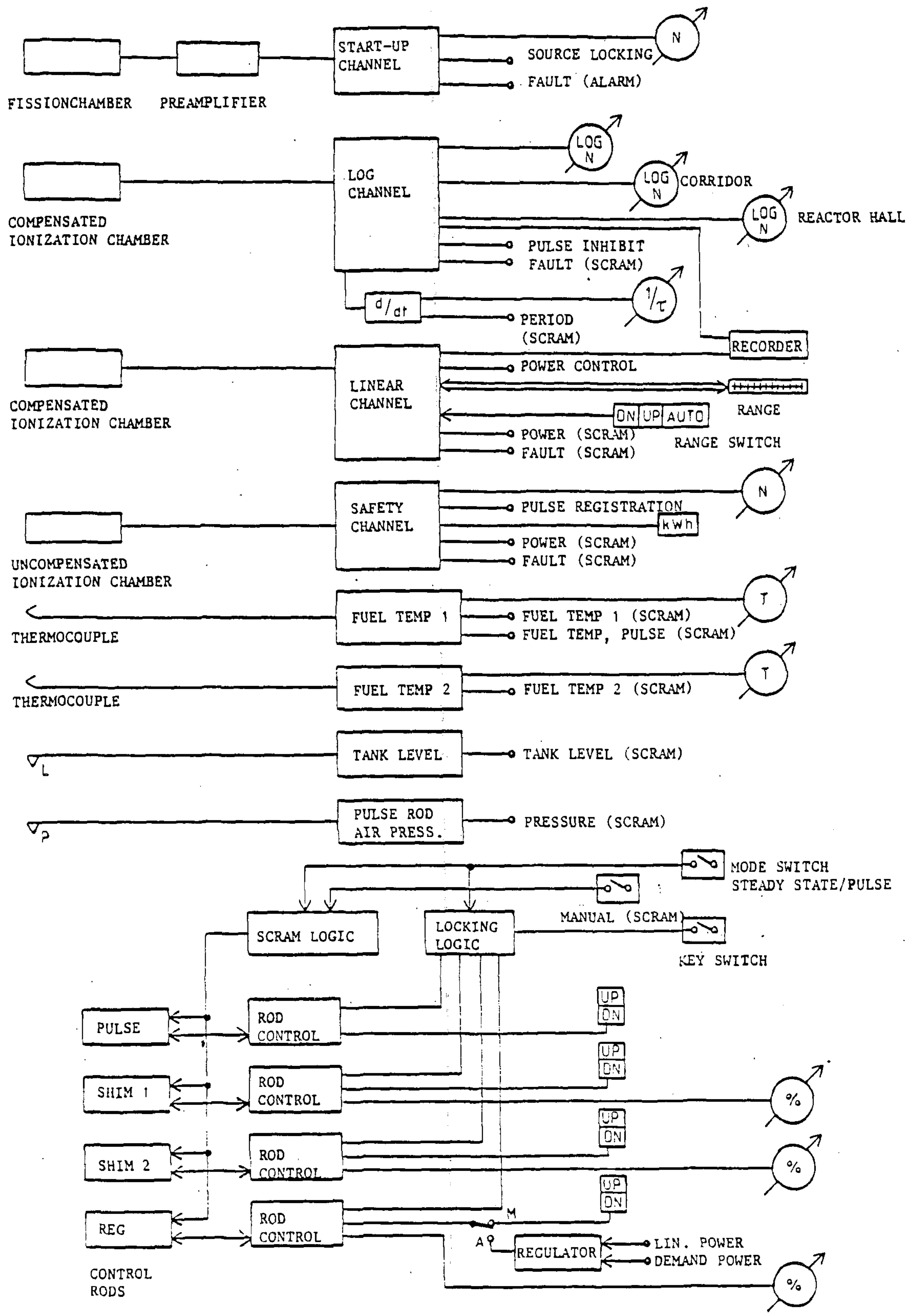

Fig. 1 Block diagram for nuclear measurements, power control and some scram actuators (TRIGA Mark II, Finland).

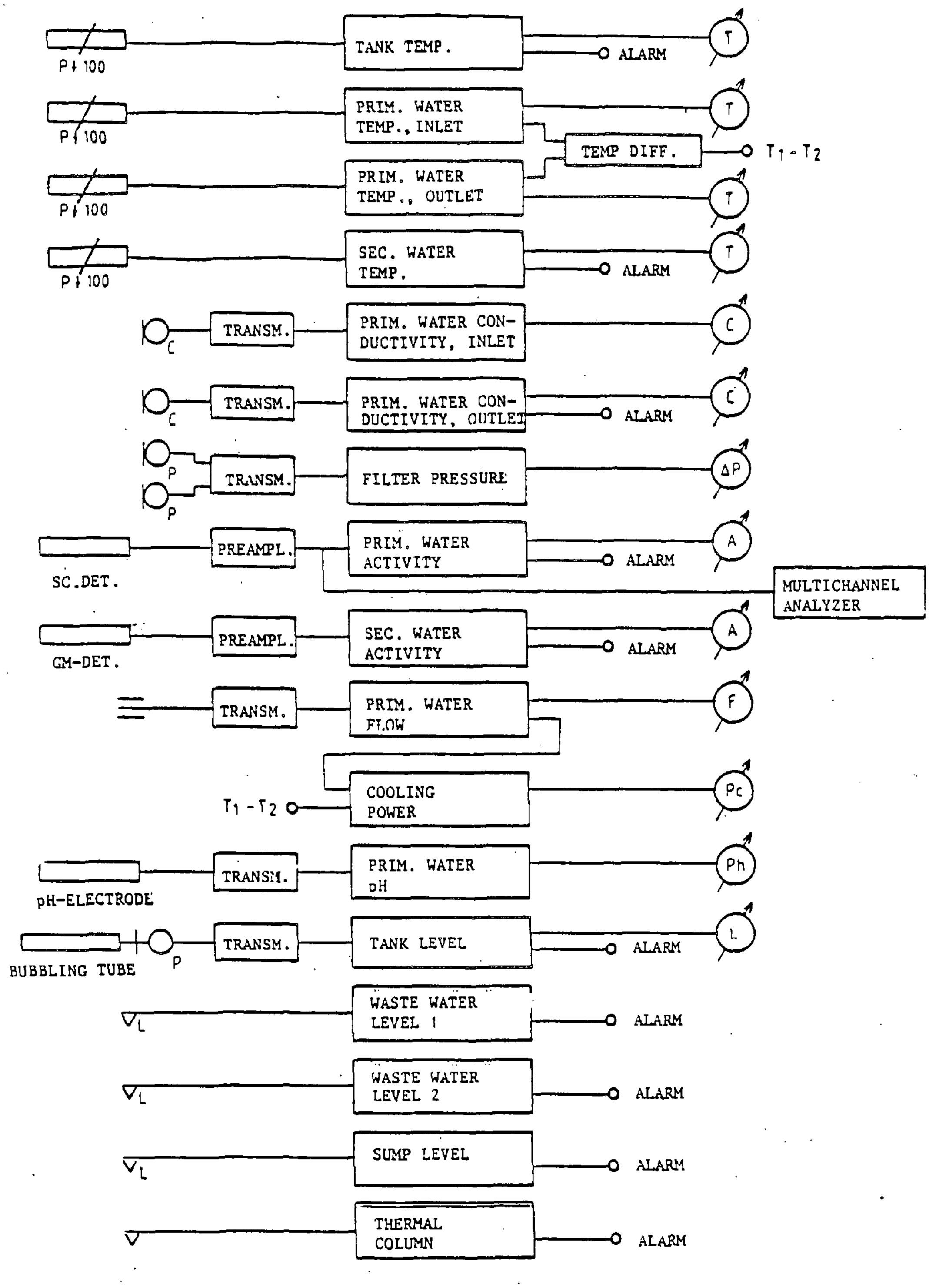

Fig. 2 Block diagram for the process parameter measurement channels (TRIGA Mark II, Finland).

Fig. 3 ← View fron the new control room with the control console in front and the instrument racks at the right (TRIGA Mark II, Finland, Jan. 1982).

Fig. 4 ↓ Control console panel in the new instrumentation.