Research and test reactors are complicated systems, whose use in developing nuclear science and engineering, as well as related areas, is constantly extending; there are extensions to research on neutron and nuclear physics, solid-state physics, radiation biology and medicine, and neutron activation, which would be impossible without appropriate research reactors.

A major line with research reactors has always been experiments directly related to nuclear power developments. Particular importance now attaches to radiation materials science and research on processes occurring in fuel and constructional materials, particularly the interactions between them, which involve tests on major core units for power reactors, and the determination of reliability and limiting working parameters under actual conditions of use and in possible accidents.

The first research reactors were designed and built in the USA and USSR in the 1940s to demonstrate the scope for controlled chain fission and to research the production of the artificial fissile element plutonium. They soon became the prototypes for the first commercial reactors (plutonium producers).

There is now more than 40 years' experience with designing, building, and operating research reactors, which has shown that they are safe and reliable. The first Soviet research reactor was the F-I, which was started up on 25 December 1946 by I. V. Kurchatov, and up to now has been used in various researches, including as a standard source for neutron fluxes for certifying sensors and instruments.

According to IAEA data, up to the end of 1986, 522 research reactors had been built in 61 countries, where the designs had been developed in 40 countries. Out of these, the USA had built and used over 200, of which 115 are currently operating. In this country, over 60 research reactors have been built, most of which are in use in research centers in this country or abroad.

One cannot say that there have been no accidents or emergencies at research reactors, since there have been in this country and elsewhere, but these accidents, like ones on critical assemblies, have been local. There have been natural improvements in responsibility and scientific approach to safety throughout human activity, particularly as regards developments in new technologies, which applies fully to research reactors. Improved reliability and nuclear safety have been particularly important topics since the accident at Chernobyl power station.

Although the topics are complicated and numerous, particular attention is required to some features specific to research reactors.

Some research reactors are located in large cities or near them, so they must have the necessary safety not only for staff but also for adjacent populations.

Most research reactors were designed and built in the late 1950s or early 1960s, when there were no strict specifications laying down the working lives of major units: heat exchangers, pipes, and tanks, nor was there any reliability analysis for emergency protection equipment or the response of such equipment to faults. There were also no specifications for the radioactivity in the first-loop coolant. In order to extend facilities, the power levels in most such reactors have been raised, and now they have attained values several times the design ones. The modifications have concerned only some of the equipment. Changes have been made in reactor design and facilities, and possible accidents and their consequences have been examined by the operating organizations on simplified models often having insufficient basis for protection and localization systems. The possibilities of failure in such systems in accidents have not been considered at all.

The number of power reactor types is small, whereas research reactors have a wide range of designs related to their purposed and optimum power. There are particular features in safety analysis for each type here.

Here we consider improving safety and reliability mainly for swimming pool-type reactors, which are the most common.

Safety Aspects of Research Reactors

1. The uranium in a research reactor is always highly enriched (about 90%), and even after the proposed reduction, the enrichment remains high (about 20%), which is due to the need to attain high specific power and high neutron flux density. Such reactors are much smaller than power ones because of the higher $K_x$, which is naturally related to the higher core $^{235}\text{U}$ concentration.

The prompt temperature coefficient of reactivity due to fuel heating is small, which greatly increases the heat accumulation during rapid run-up (when $\rho \gg \beta_{ef}$), and the reactivity cannot be compensated by the Doppler effect even with the fuel heated to the melting point if the introduced reactivity exceeds $\beta_{ef}$ and the power level rise continues until the fuel rods fail. Some research reactors, particularly solution ones and the TRIGA type, in which part of the moderator is homogeneously mixed with the fuel, can have a considerable prompt temperature coefficient, which substantially improves the safety, but the power levels in such reactors are low, which restricts their use. The amount of plutonium accumulating during a run is small, which reduces the radiation effects from accidents.

2. The reactivity margin in a research reactor is high and sometimes attains $25\beta_{ef}$, which is partly due to the use of highly enriched uranium, since a low breeding factor requires a large reactivity margin in order to obtain the economically desirable burn-up, while it is also necessary to balance out the negative reactivity introduced by experimental devices. The large reactivity margin means that there must be many control rods, but in practice the situation often is that the number of rods is small but the weight of each is considerable. Naturally, the consequences of unplanned removal of such a control rod may be undesirable and should be eliminated by suitable engineering design. The important point is that the reactivity margin can vary widely with the experimental program.

3. The performance of the fuel-pin assemblies in a research reactor is high, usually much higher than that in a nuclear power station. For example, some swimming-pool reactors have values of $4\beta_{ef}$ (the effect from replacing a spent assembly by a fresh one is about $2\beta_{ef}$). In the HPUR (USA), the entire core consists of one assembly. On the other hand, in the RBMK, the effect from replacing a spent assembly by a fresh one is only $0.02\Delta k/k$. As a consequence of this high performance, refuelling operations at research reactors are hazardous.

4. Most research reactors have horizontal channels to extract neutron beams, which lie at the core center level. This is a major design feature. Therefore, an accident involving fast sealing failure in such a channel can lead to the core drying out almost completely and can have major consequences. Some changes can be made in the design such as a guard jacket, or a continuous tank containing cavity-type displacers opposite the horizontal channels, and so on, which can improve the safety considerably. It is true that this involves some loss in neutron flux density.

Such measures cannot be taken at operating reactors, but they should be envisaged as far as possible for ones being newly built or modified. This has not previously been done,