Reprinted from MECHANICAL ENGINEERING, Vol.4, No.2: 124-126.
February 1955

A Reactor Emergency

. . . *with resulting improvements*

By G. W. Hatfield

Atomic Energy of Canada Limited
Chalk River, Ontario, Canada

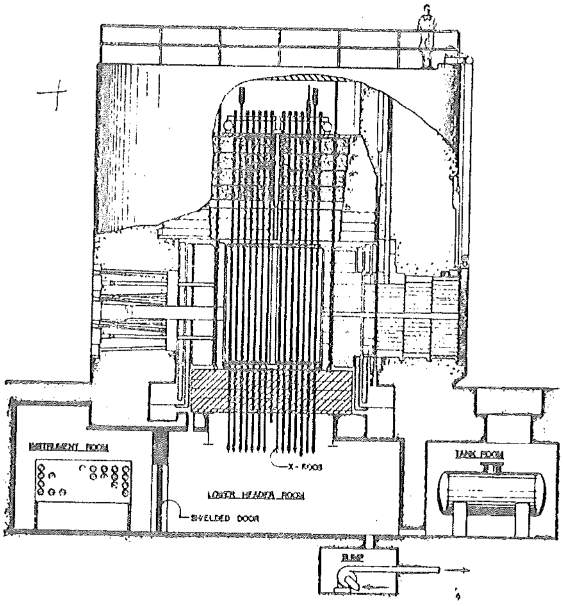

Fig. 1 Cross section of the NRX reactor which had been in operation for five years when a mechanical failure caused a near-disastrous emergency

On December 12, 1952, a low-power experiment was being carried out in Canada's NRX nuclear reactor which had been operating for 5 years. Owing to a complex chain of events, a mechanical failure occurred in the shutoff-rod system which resulted in a power surge. About 10 per cent of the uranium rods in the reactor had temporary connections made to them to permit a reduced flow of cooling water for experimental purposes and the overheating resulting from the power surge caused the reduced flow of water to boil to the extent that some of the uranium and aluminum melted. Breaks occurred in some of the calandria tubes as well as uranium sheaths and water tubes on the uranium rods, thereby permitting cooling water to flow into the basement beneath the pile. Thus some uranium metal became exposed to the cooling water and fission products were leached out into the water flooding the basement.

The NRX Reactor

Fig. 1 represents a cross section of the NRX Reactor. Starting at the top, is shown a revolving steel plate used for the removal of rods, the top cooling-water header, the four concrete biological shields, and below that the three steel water-cooled thermal shields. The aluminum vessel in the center is approximately 8 ft diam and 10 ft high with tubes rolled into the tube sheet at the top and bottom similar to a calandria used for heating in a vacuum pan. This vessel contains the heavy water which is used as a moderator. Below the aluminum tank are four water-cooled steel thermal shields followed by a lead-masonite shield and bottom outlet cooling-water header. The rods are approximately 31 ft in over-all length with 10-ft uranium sections that pass through the tubes in the heavy-water area of the aluminum tank. The aluminum tank is surrounded with graphite which acts as a neutron reflector and steel shields surround the graphite with approximately 8 ft of concrete as a biological shield beyond the steel shields.

At the time of the accident the cooling water flooded into the basement at the rate of 300 gpm, at one stage rising to a level halfway up the instrument-panel board.

Fig. 2 represents a uranium-rod assembly inserted in the reactor. It is to be noted that air passes up through the calandria tube around the water sheath of the uranium rod, which air removes a small portion of the heat generated. Fission products which escaped into this air stream were negligible at the time of the accident, being mostly of a short life.

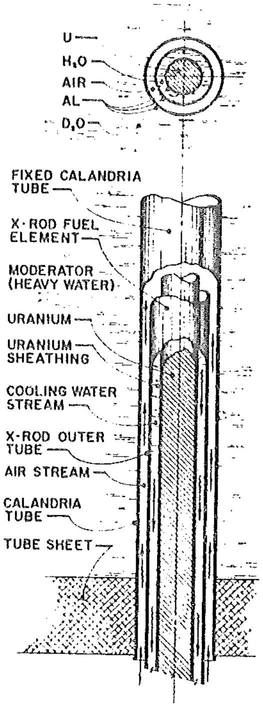

Fig. 2 Uranium-rod assembly inserted in reactor

Emergency Measures

Fig. 3 indicates the problem which faced the staff and represents two different examples of ruptured rods where cooling water in contact with bare uranium was flooded into the basement. It was not considered safe to shut off this flow of cooling water as the condition of the uranium was not known. The main concern was the

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Contributed by the Safety Division and presented at a joint session of the Safety Division, Nuclear Energy Application Committee, and Power Division at the Annual Meeting, New York, N. Y., November 28–December 3, 1954, of The American Society of Mechanical Engineers. (Condensed slightly from ASME paper 54—A-224.)

fact that some of this uranium was highly irradiated and, if this uranium were not cooled, it would heat up to the point where the metal would oxidize rapidly and even catch fire. Therefore, as the first precaution, the cooling water to all the rods in the reactor was decreased to a minimum by gradually throttling the flow of water through the valves leading to the main header. In this manner the flooding of the basement was decreased from 300 to 60 gpm. This was followed later with shutting off the cooling water to the rods which were not ruptured after installing special headers as shown in Fig. 3. Here, needle valves were used to control the flow at the top and bottom of each ruptured rod. After this installation was completed the leak to the basement was decreased to 14 gpm.

At the same time, while we were endeavoring to decrease the flooding below the reactor, the active water which already had collected in the basement was being pumped to large storage tanks outside the main building and these tanks were rapidly becoming filled to capacity. A decision was made 5 days after the accident to pump this active water out to the disposal area where the soil was a mixture of sand and clay. In zero weather a pipe line $1^1/_4$ miles long with the necessary pumping facilities was installed in the next 5-day period. Approximately 1,000,000 gal of active water containing 10,000 curies of long-lived fission products were pumped through this pipe line to the disposal area. (For comparison, some 1500 curies of radium have been produced in the world to date.) A check was kept on the activity in the water draining from the disposal area and no detectable activity has been found even in the creek draining the area to a small lake.

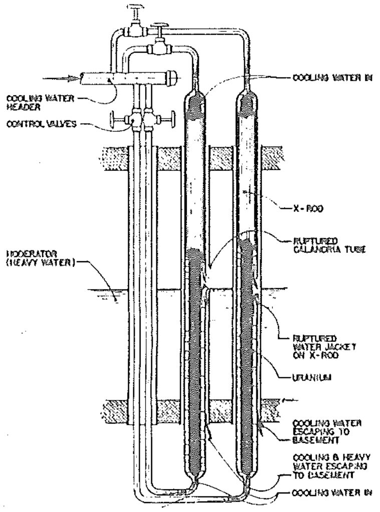

Fig. 3 Two different examples of ruptured rods which were involved in the accident

Dismantling the Reactor

It is difficult to describe the multitude of problems associated with radioactivity with which we were faced during the next 8-month period when dismantling the reactor. These problems included the design and fabrication of many special tools for use by remote control for cutting and removing the ruptured rods out of the reactor as well as the removal of the stainless-steel water headers and valves below the reactor which were badly contaminated, and the decontamination of thousands of square feet of concrete throughout the reactor building.

Removing the Aluminum Calandria. The procedure used for removing the aluminum calandria from the reactor will be described. This calandria is probably the largest radioactive source that has been handled to date.

Owing to this high level of radioactivity, all operations had to be controlled remotely.

In Fig. 4 a lifting jig was first lowered down on top of the calandria. This jig had dogs hanging below, designed in such a way that when the dogs entered the holes through the calandria tube sheet, they slipped outward hooking onto the underside of the sheet when a lifting strain was applied to the jig. The overhead crane hook was lowered and engaged by remote control to the hook on the lifting jig. The calandria was then raised out of the hole and, with the use of long ropes as guides, it was moved across the pile by the crane and lowered into a canvas bag which was attached to a skid turned up on one end against the side of the reactor.

The skid was then lowered into a horizontal position on the floor of the reactor building by slackening off on a yoke which was attached from the outer face of the skid to the inner face of the reactor and thence out to a bulldozer which acted as a winch. After the skid was in a horizontal position on the floor, the pin was withdrawn from the outer end of the skid by means of a long rope attached. This released the skid from the yoke.

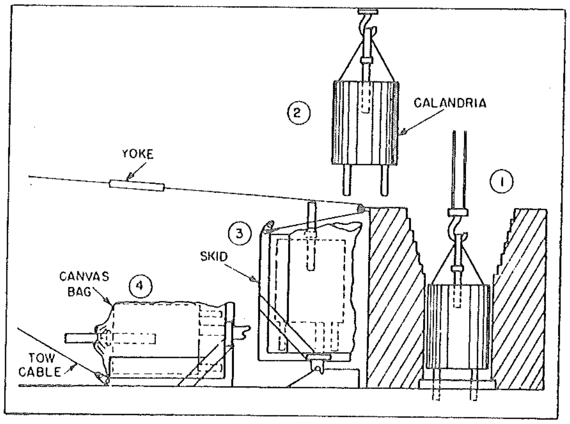

Fig. 4 Method of handling contaminated calandria tank, illustrating its removal to the disposal area

The skid was then towed out of the reactor building, with all remaining ropes attached, with the use of a grader, through the plant proper to the disposal area about $1^1/_2$ miles away.

Radiation Measurements. Radiation measurements on this tank indicated 20 roentgens per hr in contact with the top tube sheet, 100 roentgens per hr in contact with the side of the tank, and 300 roentgens per hr in contact with the bottom tube sheet.

In order to appreciate the magnitude of this radiation measured in terms of roentgens per hour, if one hundred people were to receive a total body irradiation of 400 roentgens, at least fifty of these people would definitely have received a lethal dose. For this reason the normal health tolerance has been limited to 300 milliroentgens per week which is applied as a very rigid control on all employees working with radioactivity. However, had we attempted to apply this rigid tolerance when working with the activities involved due to this accident, we would have very quickly run out of manpower to handle the job.

Reconstructing the Reactor. On reconstructing the reactor all of the equipment removed was decontaminated and used over again, such as shields, water headers, pipes, valves, instruments, and so on, with the exception of the aluminum tank and one steel shield immediately above the tank which were purposely damaged beyond repair in order to simplify the removal of the ruptured rods. These two pieces of equipment were replaced by new equipment.

Additional Safety Measures

From investigating the causes leading to the power surge in the NRX Reactor on December 12, 1952, and taking advantage of our experience in dismantling and reconstructing the reactor, a number of alterations were made in our operating procedures and in the design of the reactor to improve the safety and simplify the problems of decontamination in the future. Some of these improvements are as follows:

1 Keeping in mind that the NRX Reactor is essentially a research unit and not a production unit as would be the case for a power reactor, we have formed in our operating organization a small group which we call "Reactor Safeguard." The head of this group was chosen from a high level in the organization, in terms of years of experience and knowledge of operating a nuclear reactor, and this head reports directly to top management. His responsibility is to keep management fully informed in advance of any research or experimental program or any alteration in the routine operation that might affect the safety which was originally designed into the control of the reactor.

2 Previously the shutoff rods in the reactor were removed in groups when starting up the unit. At present a mechanical valve, in addition to electrical controls, has been installed, thereby providing two independent means for controlling the sequence of removal of shutoff rods from the reactor. Of course it must be kept in mind that the NRX Reactor is heavy-water moderated and the critical size is dependent on both the load in the reactor at any particular time and the heavy-water level in the aluminum tank.

3 Rate-of-rise amplifiers have been installed which automatically trip the shutoff rods into the reactor should the power increase exceed a preset rate.

4 Additional signals have been installed to indicate when the shutoff rod is neither in the up nor the down position.

5 Routine checks are made on dropping the shutoff rods; when a rod fails to drop to the down position it is removed promptly from the reactor and replaced immediately.

6 In building any nuclear reactor the ease of dismantling the unit must always be incorporated in the original design.

7 When building a reactor which requires heavy water or light water as a coolant, all surfaces below the reactor should be of a smooth finish and nonabsorbent.

Bare concrete is a very poor material when exposed to radioactivity accompanied by a liquid. The activity enters the concrete to the distance where the liquid or moisture is absorbed and the only method for removing this activity is by chipping and grinding away the concrete to the distance that this absorption has taken place. For this reason the concrete surface should be sealed as tightly as possible.

8 All panel boards for instruments and equipment that, of necessity, must be located below the reactor should be suspended from the ceiling above rather than attached to the floor. If equipment must rest on the floor it is essential that the point of contact between the equipment base and the floor should be completely cocooned in order to prevent active liquid from running in beneath the base of the equipment and down through boltholes or cinch anchors buried in the concrete.

9 An ideal design directly under a reactor that contains liquid is that in which a large funnel is installed to collect all the active solution that leaks away from the unit above and the material caught in the funnel should be piped to one controlled central point.

10 Whenever lead is used for shielding or protection on floors and walls under or adjacent to a reactor, design should be such that the lead is easily removed for decontamination purposes. Our experience has been that the simplest method of decontaminating lead is to melt it; by skimming the slag off the surface the major portion of the activity is removed. The decontaminated lead is then remolded for further use.

11 All horizontal surfaces in the main reactor building, including overhead girders, cranes, etc., should be sealed with a material of a smooth finish thereby easing the problem of decontamination.

12 The vertical surfaces, such as the walls of the building, should also be of as smooth a surface as possible in order to ease the problem of decontamination.

13 The ventilating system in a reactor building should be designed with enough extra inlets to provide a quick means for attaching portable connections in special locations when emergencies arise. The problem of controlling the ingested activity by workmen carrying out repairs in or around the reactor is of as great importance as the control of total body irradiation. In our case, all workmen were forced to wear respirators or fresh-air masks for a period of 10 months when carrying out the renovation of the reactor.

14 Permanent facilities in a heavy-water reactor or a light-water enriched reactor always should be available for pumping large volumes of water containing activity into a sand and clay disposal area. Pumping through ion-exchange resins also could be used for this purpose with the plan of burying these resins after they have been used. However, this procedure is far more costly.