THE CHALK RIVER ACCIDENT IN 1952*

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The Chalk River accident, in December 1952, was the first destructive accident in what was then a fairly large thermal reactor; previous criticality accidents (with one exception) had been in experimental critical assemblies. The accident occurred in the NRX reactor at the Chalk River Nuclear Laboratories, about 125 miles north-west of Ottawa (Fig. 1). NRX was a 30-MW research reactor which had then been operating for about 5 years. The accident was hardly spectacular from most points of view; no one was injured, no large area was seriously contaminated, the public was not frightened by reports of real or imagined dangers. However, this accident did effectively destroy the core of a reactor which at that time had the highest flux of any in the world. It then provided the first opportunity to explore the problems of dismantling a large reactor.

Figs. 2 & 3 show the laboratory area, which is beside the Ottawa river and surrounded by a forested exclusion zone, about 4 miles in radius.

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Figs. 4 & 5 show the NRX reactor and the building around it.

Basically, this accident was a brief power surge which had drastic consequences for the reactor only because it was being operated under special conditions. Since I assume that you are curious to know some of the ways in which apparently well-instrumented reactors can have accidents, I will describe, in an abbreviated form, the steps that led to this one. Then I will describe the immediate consequences and finally some of the problems of taking the damaged reactor apart.

To understand how the accident happened and its results, you have to know a little about the structure and control of this reactor. I will use the present tense, although some of the details of NRX are now different.

Figure 6 shows the basic structure. This differs from that of a typical light-water reactor in that the moderator - which is heavy water - and the light-water coolant are completely separate. The moderator is contained in a cylindrical Al tank. Passing through this tank are vertical tubes open to the air at top and bottom. Each fuel rod, made of metallic natural uranium and sheathed in Al, has its own built-in cooling jacket and each rod and its cooling jacket can be passed through one of the vertical tubes. A stream of air passes between the cooling jacket and the tube of the moderator vessel.

The reactor is started-up by raising out of the reactor about half of 12 boron shut-off rods that pass through 12 of these vertical tubes. The reactivity can then be adjusted by altering the height of the moderator in the tank.

These shut-off rods can be raised by compressed air and then are held up by an electro-magnet. They can be driven back into the reactor by high-pressure air. If the pressure fails they will fall under gravity, although more slowly. The rods are controlled by buttons on the control desk and their position - either up or down - is indicated by nearby lights. Some of the rods operate together in groups.

The accident occurred during a start-up procedure. Just as the first group of shut-off rods was about to be removed, an operator in the basement of the building (who had nothing to do with the start-up) mistakenly turned some air-valves which caused several shut-off rods to rise. This was immediately shown by the indicator lights in the control room. The reactor supervisor phoned the operator to stop and went down to the basement himself to make sure that the valves were properly reset. When this was done the rods should have gone down into the reactor. In fact, they went down only part way, but far enough that the lights in the control room indicated that they were down.

The supervisor in the basement phoned the control room and told his assistant to press two numbered buttons. He gave the wrong number for one of the buttons and when it was pressed, instead of resetting the air pressure as was intended, it raised four more shut-off rods. If the first group of shut-off rods had been down, as their lights indicated they were, raising four rods was a reasonable thing to do, so the mistake was not recognized.

It was soon apparent from instruments in the control room that the reactor was above critical and the power level was rising. This was surprising but not alarming since the reactor could easily be turned off by dropping the shut-off rods just raised. But when, after 20 seconds, the button was pressed to do this, only one of the 4 rods actually went down. The power level continued to climb and, after some discussion in the control room, it was decided to dump the moderator into a storage tank. Within less than 30 seconds the power-level meters were back on scale and the power dropped rapidly to zero.

Well, all that had happened was that a 30-MW reactor had gone to perhaps 100 MW for less than 20 seconds. Under normal operating conditions this might have caused no problems. But, at this particular time, the reactor was being used for an experimental measurement of the reactivity of certain rods at very low power. For these measurements the cooling flow to some rods had been greatly reduced (remember, the cooling to each rod could be controlled separately) and one rod was cooled just by air. This reduced cooling was inadequate for the power surge. The high temperatures in about 20 rods melted the uranium, the cladding separating the uranium from the cooling water, boiled the water, ruptured the jacket containing the cooling water and, in some places, ruptured the tubes that formed part of the heavy water containment.

The first indication of drastic consequences was the observation that water was pouring down into the room below the reactor. (Fig. 7) Shortly afterwards there was a rumbling noise and a spurt of water out of the top of the reactor. Radiation alarms sounded in the reactor building and air-activity monitors in adjacent buildings went off scale. Because of the air activity, the siren for the emergency stay-in procedure was sounded. About half an hour later it was decided to evacuate most of the 1800 laboratory workers from the area and this evacuation was carried out in quite a routine manner.

In the reactor building, radiation levels were now up to 1 R/h on top of the reactor shielding and up to 10 R/h in the room directly under the reactor which was gradually being filled with active water. Down-wind from the reactor, the laboratory area was strongly contaminated although much of this initial activity was decaying with about a 25-minute half-life.

The accident occurred on a Friday afternoon and over the week-end, radiation levels were surveyed and most areas where people had to go were decontaminated. By Monday, work resumed more or less normally (there was still some decontamination to be done) in all buildings except the reactor building. Exactly what had happened within the reactor and to what extent it had been damaged were still not known and this led to statements to the press that greatly underestimated the true damage.

Disposal of Active Water

Following the plant evacuation, the problem of immediate concern was the active water pouring into the basement. The cooling flow-rate to reactor rods was gradually reduced over the next few days until the leakage to the basement was only about 60 gallons a minute. Meanwhile, the basement had filled to a depth of 40 inches.

Normally, the cooling water from the reactor goes into a delay tank before being discharged to the Ottawa river. It was decided to empty this 280,000 gallon tank into the river and to pump the water from the basement into the tank through a makeshift pipe-line (Fig. 8). This provided enough time to make connections to an 800,000 gallon tank that normally formed part of the reactor cooling water supply system. While water from the basement was being pumped into that tank, an emergency pipe-line, insulated against the sub-zero temperatures, was built to take the water just over a mile from the reactor to a waste-management area where it was put into the ground. This pipe-line was finished 10 days after the accident and a million gallons of water containing 10000 curies of long-lived fission products were then pumped through it.

It was estimated that the soil in this area would retain the radioactivity long enough for it to decay before it eventually found its way back into the Ottawa river. This estimate turned out to be reasonable. The water draining this area has been carefully monitored ever since* and at no time has the activity level of water leaving the exclusion zone reached the permissible limit for drinking water. The concentration was diluted further in the Ottawa river by a very large factor.

The emptying of the delay tank into the river did release a certain amount of activity and monitors at the nearest inhabited area downstream showed activity levels of about 1% of the permissible values.

Air-borne Releases

The air that passes through the reactor, between the water-jacket around each fuel rod and the tube that forms part of the moderator tank, is discharged from a 200-foot stack beside the reactor building. Airborne activity was carried up this stack. There was no monitor in the stack and if there had been one it would almost certainly have gone off scale. The only measure of the amount of activity emitted resulted from a fortunate accident. An electrician was working near the top of a telephone pole a few feet from this stack at the time of the power excursion and his film badge read 350 mrem.

From decay measurements on contamination deposited around the site, it appeared that most of this initial airborne activity was a mixture of ^{239}U and short-lived fission products and probably came predominantly from the one rod in the reactor that was air-cooled. Unlike most of the water-cooled rods, this rod had never been irradiated before the accident. From this film-badge reading it was deduced that something between 8000 and 30000 curies of fresh fission products were discharged from the top of the stack.

The doses to laboratory personnel from this air-borne emission are not known very accurately but were certainly not large. From

*This single, large release has provided an extremely useful source for long-term studies on the movement of fission products through the ground.

the observation that unused dosimeter films were not fogged, the dose equivalent at their location was not greater than about 20 mrem. These films were stored about 400 m from the stack, in the approximate direction in which most of the laboratory employees worked.

Doses to the public were very much smaller because of the isolated location of the laboratories. In the down-wind direction, the nearest inhabited area was 12 miles away. The estimated dose equivalent there - and you appreciate the uncertainties of such an estimate - was less than a millirem. The nearest city - Ottawa - was 125 miles away and the estimated dose was 100 times smaller. No indication of activity was reported from instruments in Ottawa that had previously measured the fall-out from Nevada weapons tests.

Reconstruction

Once the active water had been pumped from the basement, the next problem was to remove the fuel rods from the reactor and this required disconnecting their regular cooling at the top and bottom of the reactor shielding. The most difficult area was under the reactor, where the contamination from long-lived fission products still gave radiation fields of 5-10 R/h. Fig. 9 shows the bottom ends of the fuel rods sticking down into this basement room and you can see what a complicated plumbing job there was. Workers were authorized to receive up to 600 mR at any one time and some were allowed to accumulate up to the 3 month limit (the ICRP limit was 300 mR/week at that time) before being taken off radiation work for the remainder of the 3-month period.

To keep individual doses within these limits much of this disassembly work had to be done by a large number of volunteers from the laboratory who were otherwise rarely exposed to radiation. Manpower was also contributed by groups of radiation workers from the Canadian armed forces, the U.S. Navy, the U.S. Naval Radiological

Defence Laboratories and the AEC. Leading one group from the USN was Lieutenant James E. Carter who was attached to a nuclear submarine then under construction. This outside assistance was of great help to Chalk River and, at that same time, the assisting organizations actually welcomed the opportunity to have teams being trained for radiation work get experience and test their equipment under real-life conditions.

By the time all the damaged fuel rods had been removed, it was clear that it was not practical to repair the damage to the tubes of the moderator tank. The challenge of replacing this tank was that no large reactor had ever been taken apart before. The tank was a cylinder 8 feet in diameter and 10 feet high and weighing nearly 3 tons. Radiation fields close to the tank were up to several hundred R/h and the problem was how to handle such a large object without incurring unacceptable radiation doses.

The plan for removing the reactor tank is shown in Fig. 10. After all the shielding plates above the tank were removed the tank was to be lifted out by an overhead crane, lowered into a large canvas bag, the bag closed, the tank tipped over on its side and the sled on which the bag rested towed away. While the tank was suspended it had to be rotated by people at the ends of long ropes and the first step was to check this guidance system with a small model of the tank (Fig. 11 to 14).

Next, a full scale model, having the same weight as the actual tank was made and most of the removal routine was practiced on this model. The actual removal, (Fig. 15,16) done after normal working hours, went quite smoothly. From starting to lift the tank to towing it away took 30 minutes (Fig. 17). The tank was towed $1\frac{1}{2}$ miles to a waste-management area, put in a trench and covered with sand. This disassembly of the reactor had taken 5 months.

The rest of the removal operation was essentially a big decontamination job, the worst problem being the concrete into which active water had soaked. In the meantime, a new reactor tank was fabricated and eventually installed. From the accident to the start-up of the rebuilt reactor took 14 months.

Public Reaction

It is interesting to compare the reaction of the newspapers to this accident with what one would expect today, on the basis of the coverage of Three Mile Island.

The day after the accident - Saturday - there were short articles - a few column-inches - in the Ottawa, Toronto and other papers with headings ¼" to ½" high, and not always on the front page. They reported essentially what they were told by laboratory management, and either they weren't told very much or they didn't consider it very newsworthy. The reactor damage was described as "a small hole, no bigger than a pin-point", a description that produced some merriment among those who had observed more than a hundred gallons a minute coming through the pin-hole.

In all the papers that I checked there was no suggestion of any worry about the safety of the public. In the circumstances this was indeed reasonable but in the climate of today it seems abnormal.

On Sunday, two reporters from the Ottawa Citizen came to Chalk River and were taken as far as the entrance hall of the reactor building. After their tour they were convinced that the rumours they had heard about highly dangerous conditions were greatly exaggerated and said so in a 3-column article, the longest article that I found in any newspaper. What these reporters found particularly convincing was the way a hand monitor, which showed them clean after the tour, alarmed instantly when a wrist-watch was inserted.

On Monday to Wednesday there were very brief articles in several papers, mainly emphasizing the loss of production of medical isotopes until the reactor was repaired. After that the accident virtually disappeared from the newspapers for 3 weeks, when reporters were invited to Chalk River and a few articles appeared on the plans to dismantle the reactor.

To summarize the causes of this accident, it resulted from mechanical failures plus poor design of the indicator system that showed when the shut-off rods were down. These technical failures would probably not have produced an accident without two human errors, both of which were well within the range of errors that people can be expected to make. These two human errors were not an accidental coincidence; the second was partly caused by the unusual circumstances created by the first.

While the short-term consequences of this accident were all destructive, there were some positive long-term effects. First, you can well believe that the shut-off system in the rebuilt reactor, and in subsequent reactors, was completely redesigned and made much more reliable.

Probably the most important benefit was the demonstration for the first time that it was feasible to replace the core of a moderately large reactor. Sixteen years later the NRX moderator tank developed some minor leaks due to corrosion and was replaced again. This time, tank replacement was a relatively routine operation and took only 3 months from shut-down to start-up of the rebuilt reactor. Whereas the dismantling after the accident resulted in a collective dose equivalent of about 2600 man-rem, the second dismantling was done at a cost of 117 man-rem. Of course, the conditions were hardly comparable. Later, the core of a larger, 200-MW research reactor at Chalk River was replaced at a cost of 176 man-rem. The practical life-time of such reactors is therefore determined by their usefulness and by economic factors rather than by physical deterioration. Finally, these successive reconstructions provide some practical experience on which to plan the decommissioning of large power reactors.

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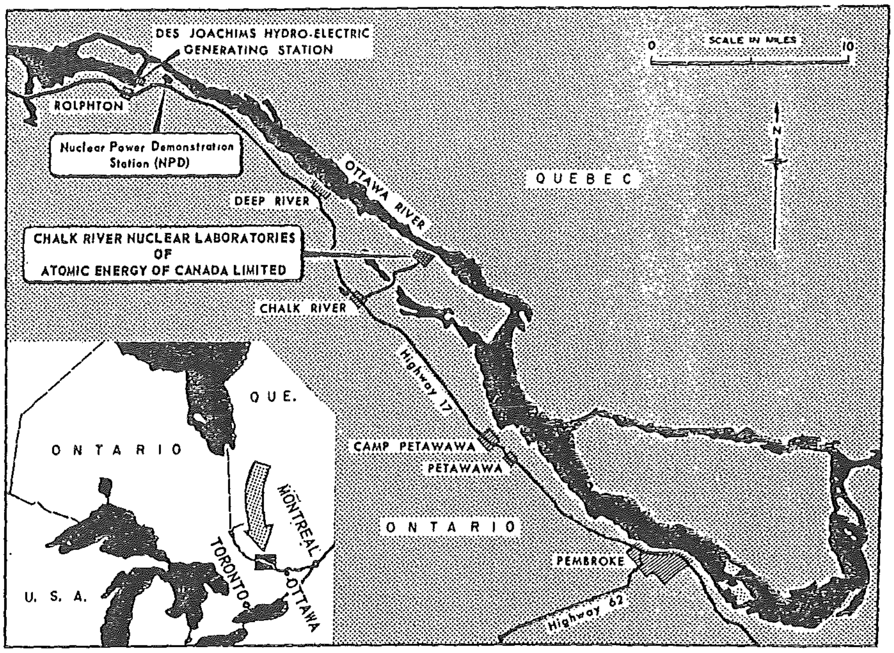


Fig. 1

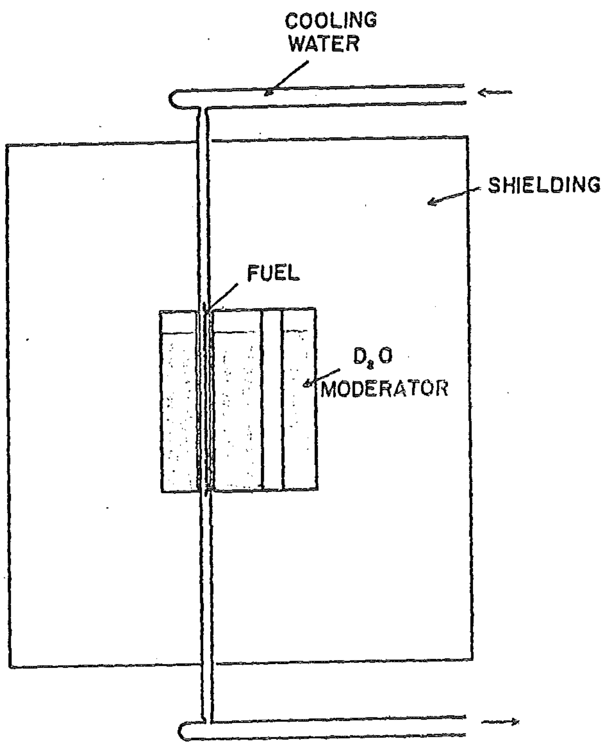


Fig. 6

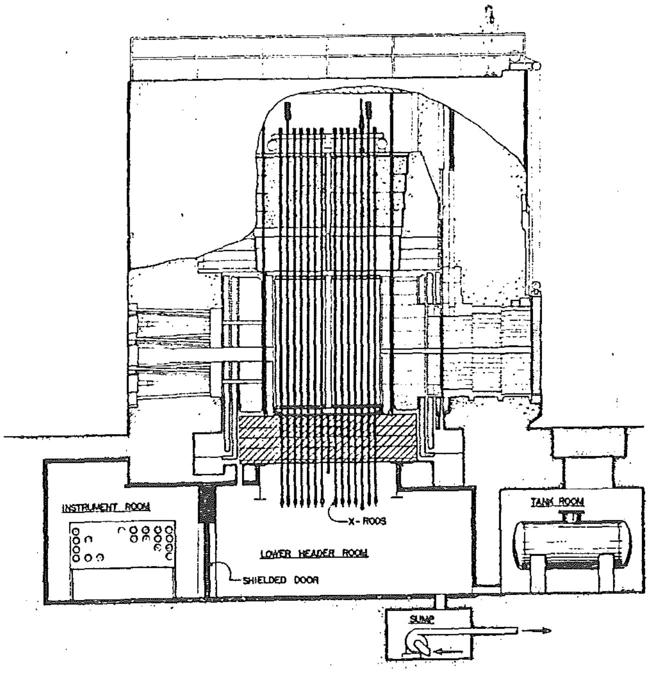

INSTRUMENT ROOM
X-RODS
LOWER HEADER ROOM
SHIELDED DOOR
TANK ROOM
SUMP

Fig. 7

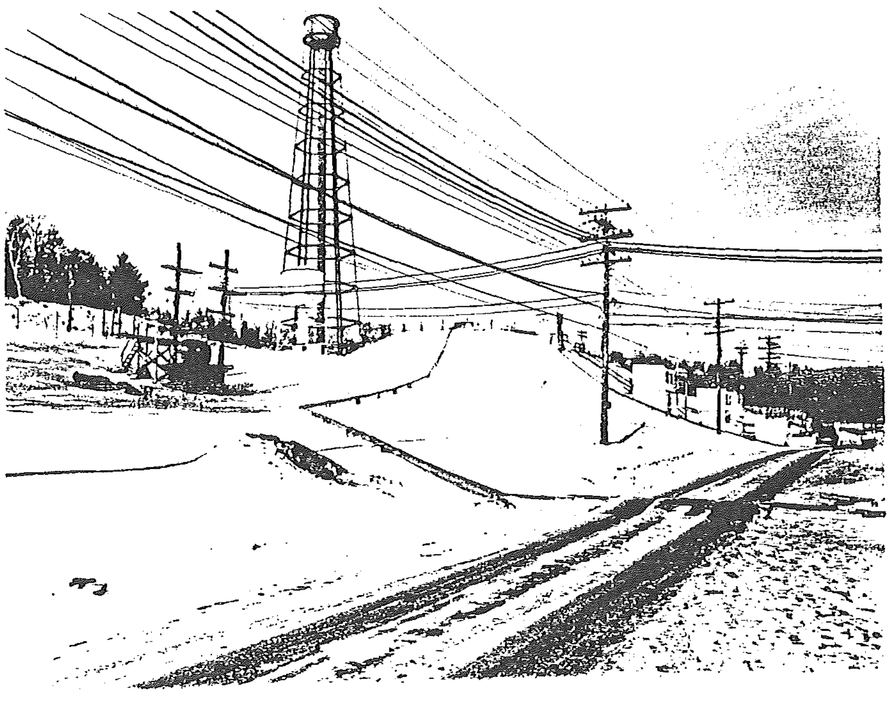
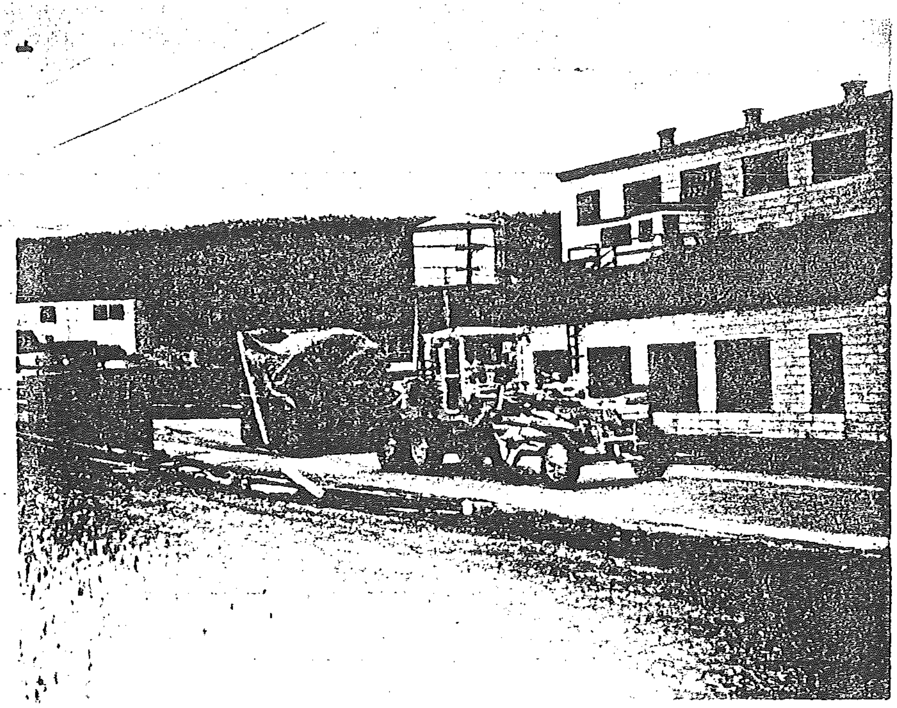


Fig. 8



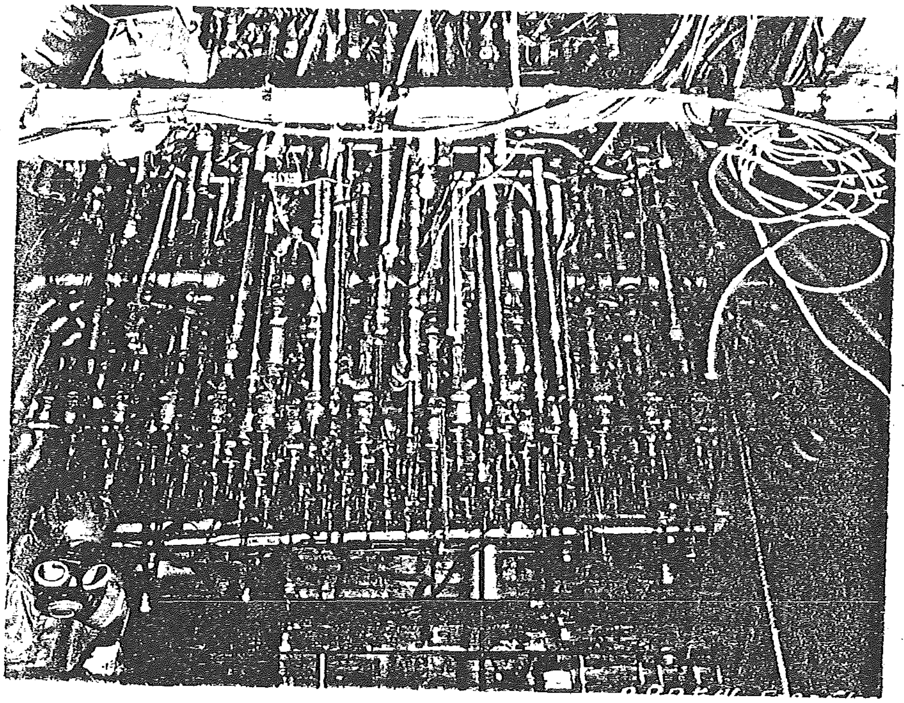


Fig. 9

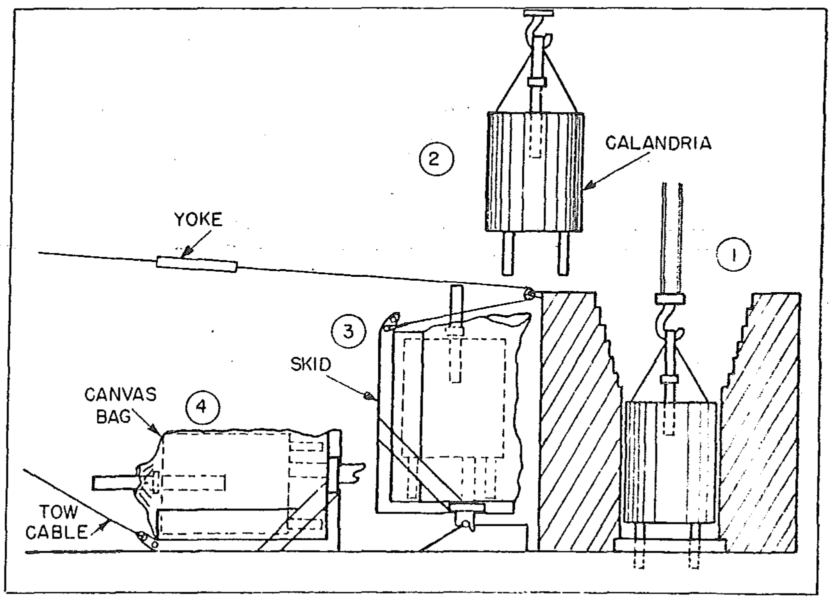


Fig. 10

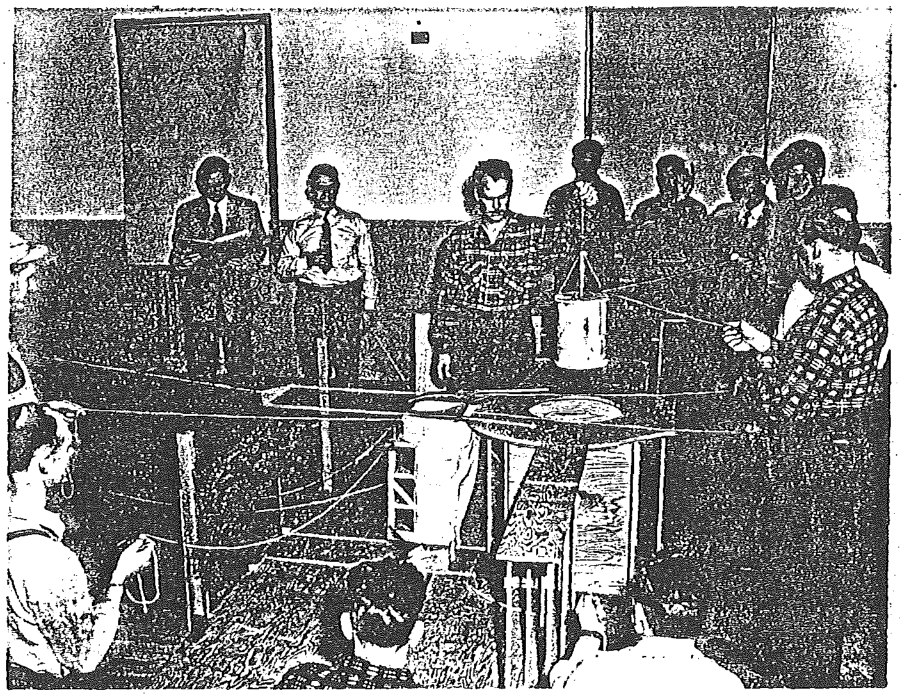


Fig. 11

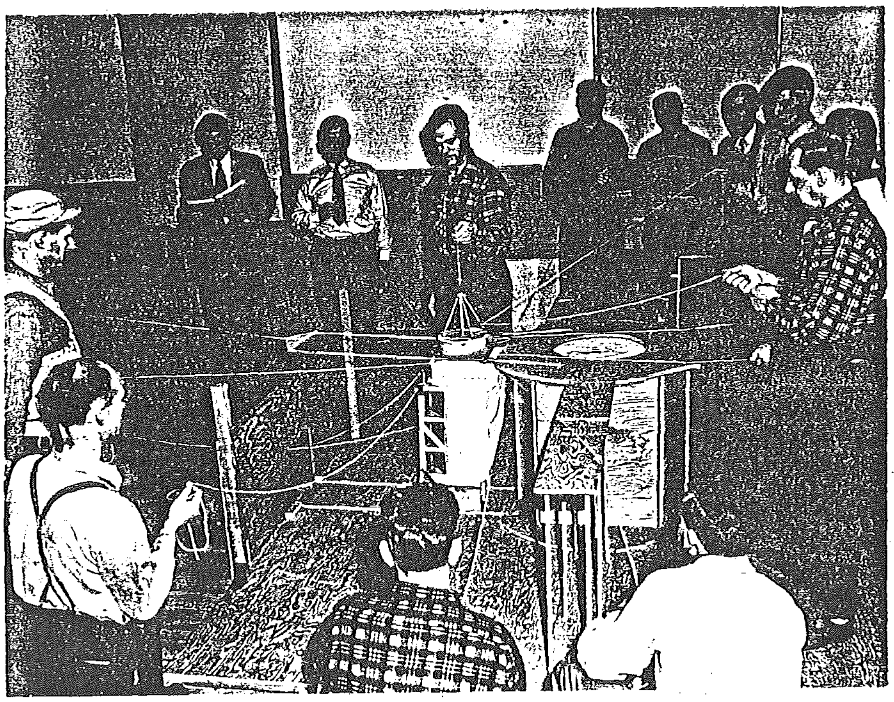


Fig. 12

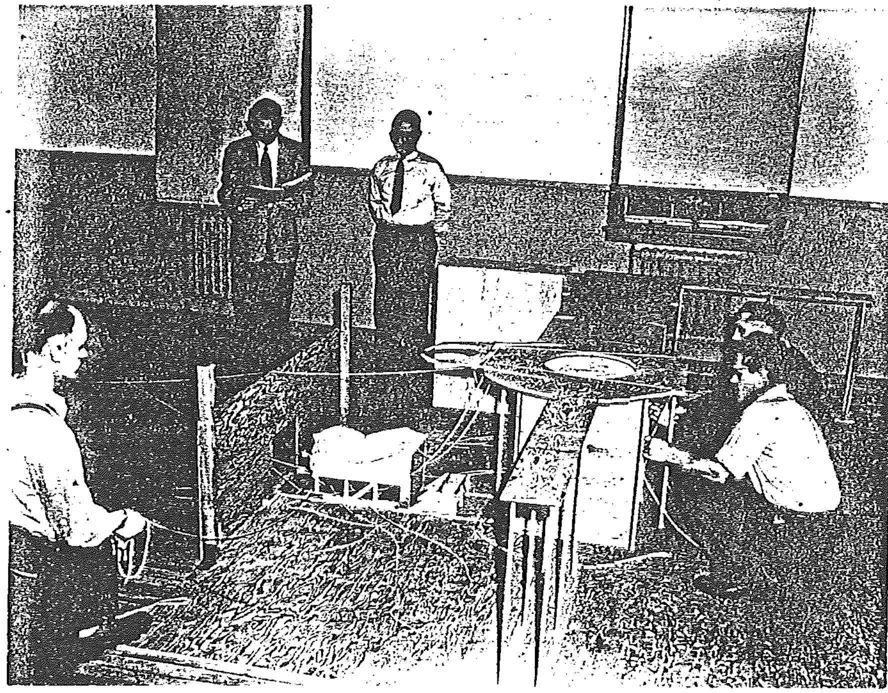


Fig. 13

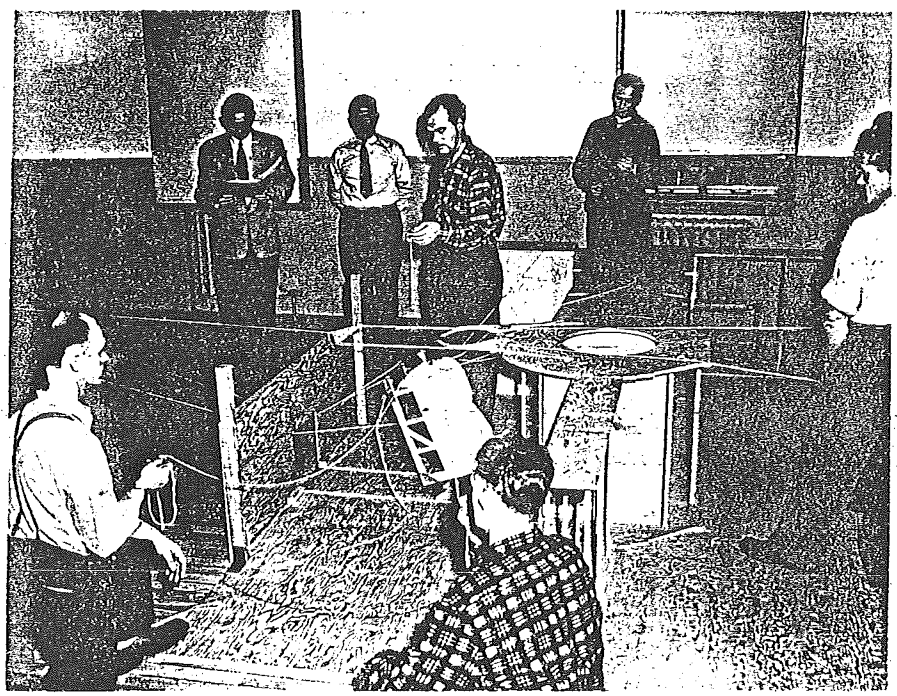


Fig. 14

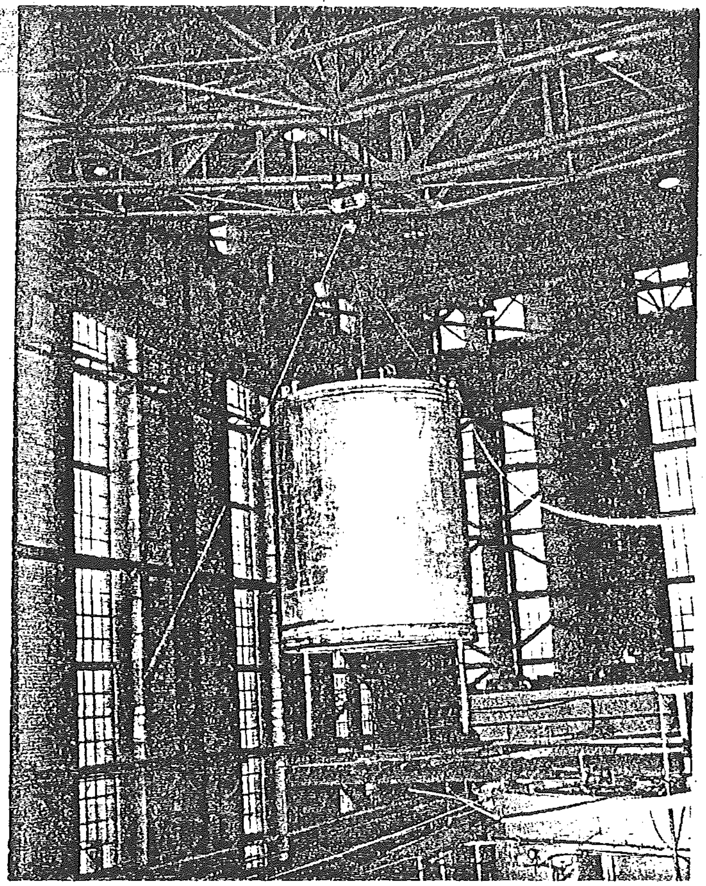


Fig. 15

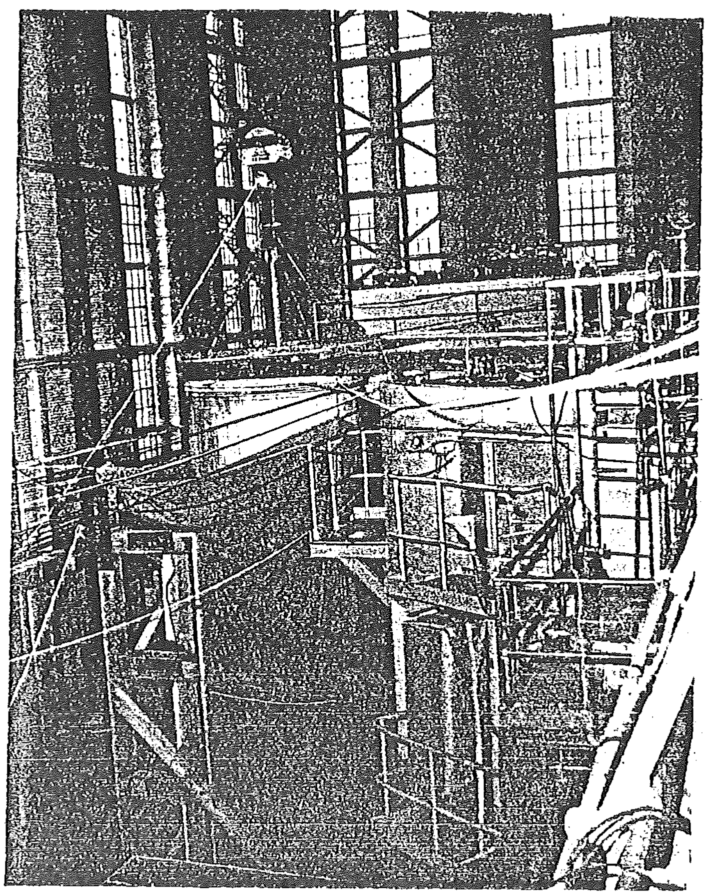


Fig. 16