THE ACCIDENT TO THE NRX REACTOR ON DECEMBER 12, 1952 (Part II)*

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ABSTRACT

Problems which faced the operating staff as a consequence of the NRX accident are discussed. These include containment of active water, cooling of broken rods, and assessment of damage. Information is given concerning the state of the fuel-rod assemblies and calandria. It appears that the major damage followed boiling of cooling water. Explanations are presented of some of the observed phenomena, in particular a sudden rise of the gasholder, and some details of fuel-rod behavior.

1. INTRODUCTION

The course of the accident to the NRX reactor on Dec. 12, 1952, has been described in Part I of this article,[1] presented in an earlier issue of the Journal. The story of the events through the next few weeks is continued here.†

The most urgent and serious problem facing the operating staff was containment of the active water leaking from broken rods. Preservation of heavy water was important but not unduly difficult. Investigation into the cause of the accident, assessment of damage, and preparation for restoration were also matters requiring attention.

The possibility of repairing the damaged heavy-water tank (the calandria) could not be lightly dismissed since some uncertainty existed as to whether a new calandria could be installed. Feasibility studies of calandria replacement, based on design drawings and photographs taken during construction, were considered. Meanwhile the work of rod removal and damage estimation was carried out with the proviso that the calandria must not be further damaged. Replacement seemed a foregone conclusion from the time of the accident, but the decision was too important to be taken hastily.

2. LIGHT-WATER PROBLEM

The escape of cooling water carrying fission products from damaged rods was the cause of grave concern for some 10 days after the accident and created the major decontamination problem that had to be faced in the subsequent restoration. The cooling system was operating with a pressure of 175 lb/sq in. One hour after the accident this was reduced to 40 lb/sq in., but meanwhile a large volume of very active

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†Descriptions of the reactor will be found in references 1 to 4.

water had been deposited in the basement. Even with the reduced head an appreciable flow continued. Within 3 hr the floor throughout the basement was awash and pipe trenches were flooded. During the course of the next few days, in spite of all efforts, this flood reached a depth of 40 in. above floor level. At about 24 in. depth the water had access to other areas: the gasholder room and the two rooms containing the heavy-water storage tanks. Activity from the water settled out in all these areas, penetrating below the surface of concrete. The radiation and airborne activity arising from this contamination impeded work and required a large decontamination effort.

One principle laid down concerning the light water was that the conditions of the damaged rods were not to be altered. Where the rods were dry through interruption of the water they were to remain dry, and, conversely, the rods which were wet were to be kept wet. The reason for these precautions was the remote possibility of a fire if uranium hydride, or the metal initially heated by fission products, oxidized rapidly. The hydrogen released from reaction with water could also burn in air. The resulting release of activity would have been serious.

The system was eventually set up so that a pressure of 8 lb/sq in. existed at the top header, the only flow being replacement of water leaking from damaged rods. (Undamaged rods were presumably cooled by convection maintained in the rod sheaths and headers because of the radial variation of heat output across the calandria.) The leakage rate was then about 1 gal/sec. The accumulation of this active water still threatened to create a critical situation.

As a temporary expedient, one of the delay tanks, having a capacity of 280,000 gal, was emptied to the river, and an emergency installation was set up to pump water from the basement into the tank. This postponed the crisis for a few days. In addition, a pumping system, arranged to return leakage water to the system, had been installed. Because such recirculation would have contaminated the top header, it was considered as an emergency stand-by only. Next, the main water tank, capacity 800,000 gal, was put into service as storage after all connections with the water system had been severed to prevent possible leakage of activity through valves into the plant water system.

Meanwhile, a pipeline was hurriedly constructed to a sandy valley on higher ground about a mile away from the reactor and the river. It was thought that the water could be discharged there without risk of activity reaching the Ottawa River. When at last the pipeline was put to use, tests made on samples of sand taken around the discharge well showed that the activity was being retained by the sand, and all the active water was disposed of in this way.

As the flow from damaged rods was much greater than required for cooling, an operation was started to put a controllable flow on every damaged rod both top and bottom. (Each X rod has provision for plugging in a hose at each end and valving off the usual water connections.) Lengths of hose were connected to each rod and were brought out to a distributor where the flow could be set to a specified value of about 0.5 gal/min. The connections at the bottom involved entry to the lower header room in very high radiation levels. The task was carefully organized. To reduce the irradiation of skilled operators who would be needed later, staff from other branches of the project were trained on a model of the header and then sent in to connect the hoses. With the success of the pipeline and the installation of separate water flow to damaged rods, the light-water system was brought under control.

Because an unusually large burst of activity was carried to the river at the time of the accident, a special survey was made of river water contamination. Monitors were established at the first two water intakes down-river (14 and 23 miles). Observations showed no increase of radioactivity above the natural level.

3. HEAVY-WATER SYSTEM

The bursting X rods punctured a number of calandria tubes, permitting the entry of light water into the heavy water and also the escape of heavy water (Fig. 1). After dumping of the heavy water was complete, the level in the storage tanks continued to rise slowly, indicating that water was running down from the calandria. The dump valves and a manually operated valve between the dump valves and storage tanks were closed. (The handle of this second valve is in the basement and its closing represented the first deliberate entry to high-radiation fields.) As slow leakage of water through the valves was indicated over the next few days, the connection between the calandria and storage tanks was broken and blanked off. The relatively simple operation of undoing a flange and inserting a diaphragm required about twenty men in well organized relays owing to the short working time in the radiation field and the cumbersome clothing, including gas masks.

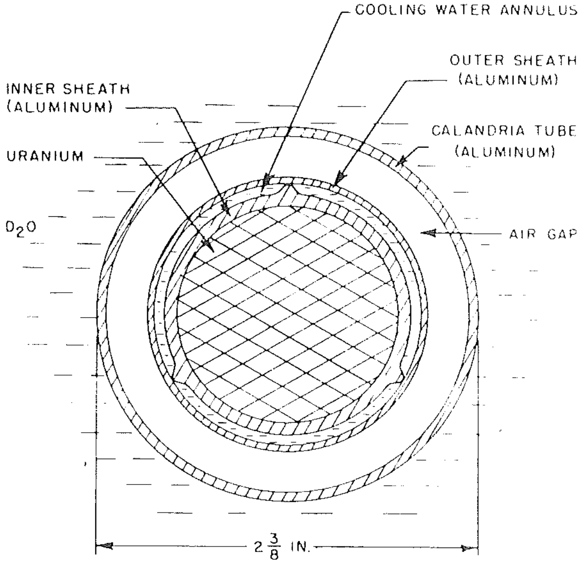

Fig. 1—Cross section of rod structure and calandria tube.

Before the isolation of the storage tanks, they had overflowed by way of a helium vent line to the gasholder, where about 6000 lb of highly active water containing 24 per cent heavy water was subsequently found in the gasholder seal.

Uranium from the burst rods entered the calandria, carrying with it fission products and plutonium. The heavy-water system had to be dismantled for decontamination, and the heavy water itself was decontaminated and upgraded. The loss of heavy water amounted to only 7 per cent, the smallness of this loss being attributable to the quick dumping to storage tanks and the blocking of the ruptures in the calandria by the influx of light water.

4. HELIUM SYSTEM

An atmosphere of helium at a pressure of 12 in. water gauge is maintained above the heavy water by a gasholder with a capacity of 550 cu ft. Normally, when heavy water is dumped, helium flows from the storage tanks to the calandria, the gasholder merely riding on the system. Loss of helium pressure was noticed during the dumping. Since a possible interpretation was blockage in the return helium pipe, causing a partial vacuum as the calandria emptied, the dumping was stopped momentarily to prevent collapse of the calandria. Dumping was resumed when the gasholder was seen to be emptying.

The subsequent behavior of the gasholder has not been completely explained up to this time, although a possible mechanism has been proposed. The height of the gasholder dome is recorded by a standard recorder which prints every 15 sec. Figure 2 is based on an analysis of the record.[5] Three intervals have been marked, of which A is the steady fall occasioned by rupture of the calandria tubes. The sudden jump to 48 in. during B is the phenomenon to be explained. The long stay at 48 in. and the pause at 24 in. during C are probably due to mechanical jamming. The rapidity of descent during C could occur only if oil were missing from the seal, and this is consistent with the early observation of oil on the floor in the gasholder room.

The gasholder is connected to the rest of the system by 2-in. pipes. The piping layout is not simple, involving condensers, elbows, interconnections, etc., but an equivalent length of pipe from gasholder to calandria might be about 75 ft. The weight of the dome is 4 tons, and its area is 133 sq ft.

For the dome to have been lifted in the normal manner would have required the supply of over 500 cu ft of gas within 30 sec, and no suitable source is known. An alternative explanation that the dome was blown up by an internal explosion is unacceptable because there is no way to account for the presence in the dome of an explosive mixture, nor for its ignition. Finally, we may suppose that a rapid influx of gas produced an impulsive pressure which gave the dome sufficient momentum to carry it to the top (the oil seal having blown at

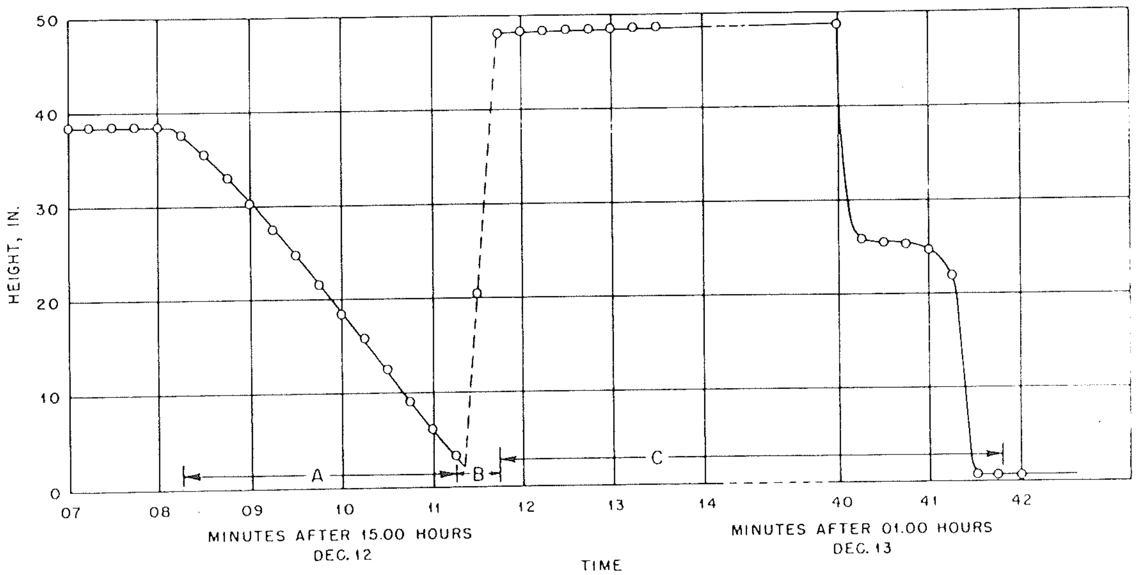

Fig. 2—The record of gasholder height. The recorder printed every 15 sec at the positions marked by circles. Guide lines have been sketched in between circles.

the right moment). The natural period of oscillation of the dome very near the bottom of its travel is surprisingly short (about $^1/_{10}$ sec). The necessary pressure would have to build up within the first quarter cycle if the dome were free, and a very large gas flow would be required. However, if the dome is assumed to have stuck initially an impulse explanation is feasible.

A possible course of events is as follows: The release of uranium from its sheath was accompanied by the evolution of hydrogen. Much of this hydrogen escaped into the calandria and may have been augmented by further reaction of uranium in the calandria. Meanwhile the helium was escaping from the calandria through several holes, and, as a result of the hydrogen content, a flame may have been burning where the gas came in contact with air. The escape of helium continued until the gasholder dome reached the lower limit of its travel (end of interval A). Air then entered the calandria and a hydrogen-oxygen explosion took place.* It appears unnecessary to specify the precise mechanism of the explosion.

There is evidence for an explosion in reports of a thud or "poof" inside the shielding and in the sudden rise of airborne activity within the reactor building. The maximum pressure reached in a hydrogen-air explosion is about 8 atm, more than sufficient to wreck the calandria. A careful study of the calandria during its removal showed no distortion attributable to such pressures. Accordingly it must be supposed that pressures did not rise above 3 or 4 atm.

As a result of this pressure in the calandria, a flow of about 30 or 40 cu ft/sec would be forced into the gasholder. Since the pressure in the calandria would fall rapidly after the explosion because of the escape of gas and condensation of the water vapor, the flow would be maintained for only a second or two. Within this interval the dome must have received a sufficient impulse to drive it to the top, and the oil seal must have blown, for if the seal had been intact the motion of the dome would have created a retarding suction.

If the dome had been free to move, the motion would have been slight. It may be supposed that a sudden rise in pressure distorted the dome

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*Exemplified by the well-known stunt of filling an inverted pail with inflammable gas, puncturing the upper end, and lighting the gas stream. At first the flame burns quitely, but after a short time the container is blown up.

and caused it to jam. The distortion would increase and provide a reservoir of gas under pressure so that when at last the dome broke free this extra gas provided the necessary impulse. At about the same time the oil must have blown out of the seal.

Even the simplest analysis leads to equations difficult to solve, but approximate calculations show that the above explanation is a possible one.

5. THE AIR SYSTEM

The air-cooling system maintains the pressure in the shield slightly below atmospheric, and discharges to the atmosphere through a stack 200 ft high. Fission products released directly into the cooling air or emanating from the water reaching the basement would be discharged from the stack. As mentioned in Part I of this article,[1] an intensely active cloud was discharged during the burst. A 9-mph west wind was blowing, and the cloud was carried along depositing active material on open spaces and buildings. The maximum of the deposit, which was nowhere very intense, lay downwind, but detectable activities were found in buildings about $\frac{1}{4}$ mile to the side. Teams of scientists surveyed the site over the weekend, and the traces of activity in buildings were cleaned up by all staff the following week.

The deposit behaved like fission products produced by a short irradiation. This would be expected because a few seconds after the power surge the fission-product activity produced by the surge was equal to that already present in the rods. Volatile fission products are in general short lived, and these are the ones which would predominate in the cloud.

Installation of filters in the outlet air duct had been scheduled for the day after the accident. This installation was carried out about a week later and reduced the risk that operations of broken rod removal, etc., would release dangerous amounts of activity into the air. Until these filters were installed, great care was taken to avoid unnecessary contamination of the air stream.

The level of particulate activity in the air throughout the reactor room and basement has varied with the work being done. Removal of parts from the inside of the reactor and shifting of massive equipment about the room have usually been accompanied by a large increase in airborne activity. As a consequence, the wearing of gas masks has been mandatory. This has increased the difficulty of the restoration considerably. Decontamination of the room, including ceiling and walls, will soon make it possible to dispense with gas masks.

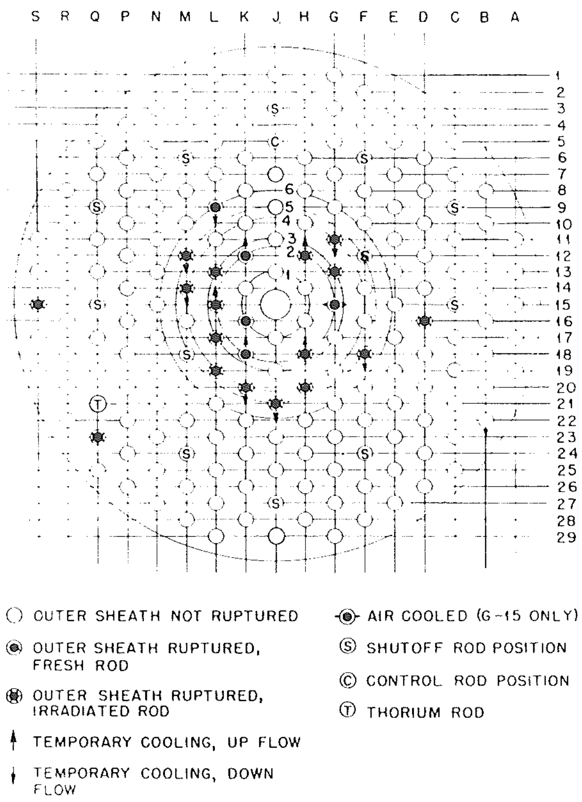

Fig. 3—A plan of the lattice. Rods with abnormal cooling arrangements are marked. With few exceptions damaged rods had ruptured outer sheaths. Some rods twisted and warped without other damage.

6. URANIUM RODS AND CALANDRIA TUBES

On a plan of the lattice (Fig. 3), the rod positions are identified by a letter and a number. They may also be assigned to concentric circles of which the first six are marked.

The six rods in circle 2 were involved in the measurements in progress. The effect on the reactivity of replacing three of these rods (in positions L-15, H-12, and H-18) with rods having different irradiation was to be measured by comparison with the effect of the cooling-water in the three fresh rods in the other positions (G-15, K-12, and K-18). Transfer between air and water cooling was required in all these rods. To reduce the risk of air pockets when the air was replaced by water, the water was fed in at the bottom of the rods and was spilled into a gutter at the top. The water pressure in these rods was thus very low, since the head was about 20 ft. Alternately, the air was fed into the top of the rod. The flow per rod was about 20 cfm of air or 1 gal/min of water. At the time of the accident one rod (in G-15) was air cooled.

Certain rods (marked in Fig. 3) had temporary cooling by downward flowing water. They were supplied in parallel with normal rods through jumpers. The pressure on these rods was normal, but the flow was considerably less than normal because of the restriction by the jumpers.

Damage may be specified roughly according to the separate or combined failures of inner sheath, outer sheath, and calandria tube (Fig. 1). Ruptures of the outer sheath are indicated in Fig. 3. These were detected by lack of pressure at the top of the rod when valved off from the top header. This information was available soon after the accident and was helpful in analyzing the leakage to the basement and as a guide in probing for more information. Damage studies were aided by an optical viewing device consisting of a mirror to be lowered into calandria tubes and an illuminator and telescope on top of the reactor. After the first few rod removals, damage was viewed and photographed (Fig. 4). In addition, a pinhole camera giving gamma-ray and optical pictures was built following a suggestion from U. S. Atomic Energy Commission and was used with particular effect in the lower header room to locate rods with excessively active ends. It was also valuable in locating "hot spots" in piping.

The rods in circle 1 were all normally cooled; two of them were very highly irradiated, and yet with a minor exception none failed. The exception was a fresh rod in K-16 in which the outer sheath had a small hole and the calandria tube a much larger hole (about 4 in. long). The rod was removed by normal procedure, and this calandria tube was one of the first examined with the viewing device. Looking out from the hole, one could see the remains of the central portion of L-15 where evidently the destruction had been violent. The appearance of the rod and the calandria tube K-16, particularly the small size of the hole in the sheath, strongly suggests that heat from L-15 contributed directly to the breakdown of K-16.

The six rods in circle 2 suffered extensive damage. In all cases central portions of the uranium and sheaths were disrupted, and with the exception of G-15 (possibly also K-12) the calandria tubes were punctured.

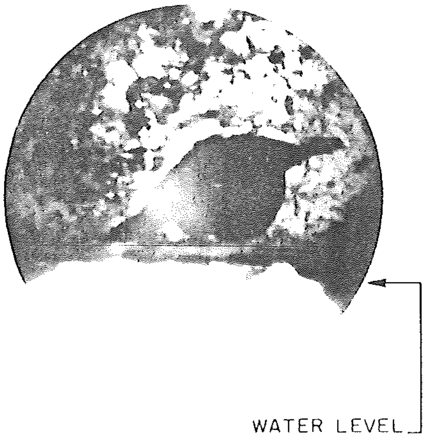

Fig. 4—A view looking east at water surface inside calandria tube M-14 photographed through a viewing device. Actual size is $1\frac{1}{2}$ in. in diameter. At the middle of the field of view is a diamond-shaped hole through which the vertical edge of a neighboring tube can be seen. The white segment at the bottom is water which filled the tube above the remaining uranium.

Circle 3 contained three fresh rods and three irradiated rods all normally cooled. The fresh rods were undamaged, and the irradiated rods were extensively damaged.

Circle 4 contained twelve rods of mixed history and cooling. The three temporarily cooled rods failed. Two out of nine normally cooled rods failed, both being irradiated rods.

In circles 5 and 6 only temporarily cooled rods failed. Beyond circle 6 failures of a minor character occurred in four very long irradiated rods. In E-19 the inner sheath burst; in the three others (marked in Fig. 1) the leaks occurred in the rolled joints at the top of the outer sheaths. One or more of these may have been the source of a leak of light water under investigation prior to the accident.

Photographs of damaged rods are shown in Figs. 5 to 9. In these photographs the scale is in inches, the zero being near the top of the calandria and 80 in. being roughly the position of maximum flux. As the scale and rod were not at the same distance from the camera, the scale cannot be used to measure transverse dimensions.

7. RECONSTRUCTION OF EVENTS

The cause of the runaway and some of the manifestations as seen in the control room have been described in Part I of this article.[1] A tendency for the power to level off at about 20 megawatts (Fig. 5 in reference 1) was followed by a sudden increase of reactivity carrying the power to about 80 megawatts. The increased reactivity probably was caused by expulsion of light water by steam. This boiling must have occurred first in the upward flow rods (circle 2) and not much later in some of the other temporarily cooled rods. Rupturing of the outer sheaths of the latter would have permitted return of light water. The damage to some of the normally cooled rods of circles 3 and 4 suggests (see Figs. 5 and 6) that the water of a number of rods inside circle 5 was boiling and being expelled by the steam.

This expulsion of light water would introduce a progressive increase of reactivity opposing the reduction by dumping of heavy water, by inrush of light water at burst rods, and by loss of uranium from the center of the reactor.

Once boiling started, steam pressure would build up because of resistance to the escape of water. This would be most marked in the rods fed by temporary connections which throttled the flow. At least two of such rods (those at M-14 and K-20) broke apart, and the upper portions with their shielding sections leaped a foot or so.

A few interesting facts and deductions are worth stating. The air-cooled rod, unlike most of its companions in the circle of maximum flux, did not damage the calandria tube so far as can

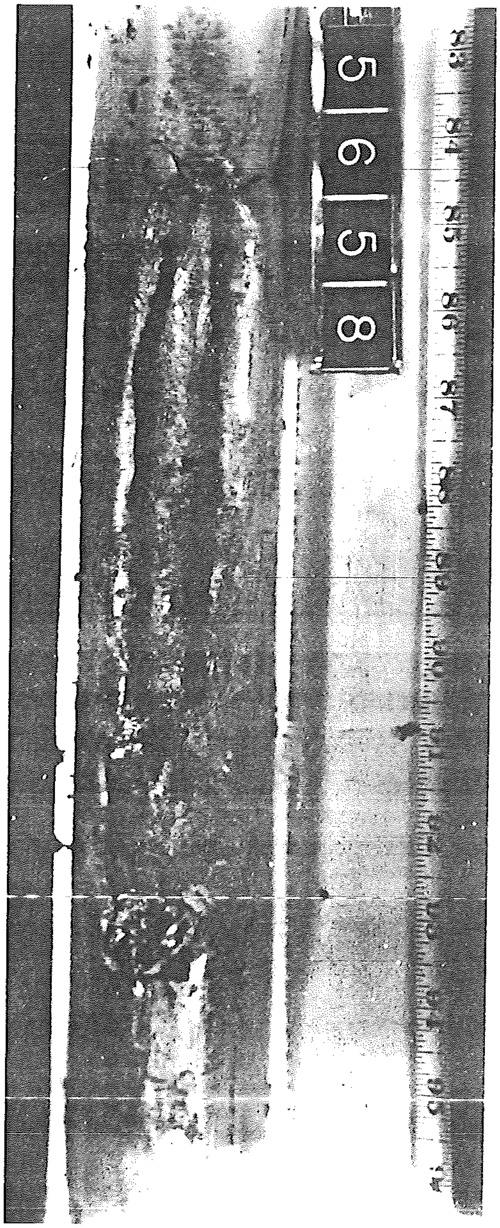

Fig. 5—The center portion of a normally cooled rod from circle 3 (G-13). After the rod was removed, viewing of the calandria tube revealed pits and stains but no major damage. This is an example of what a calandria tube can withstand. The irradiation at the center was 760 mwd/ton.

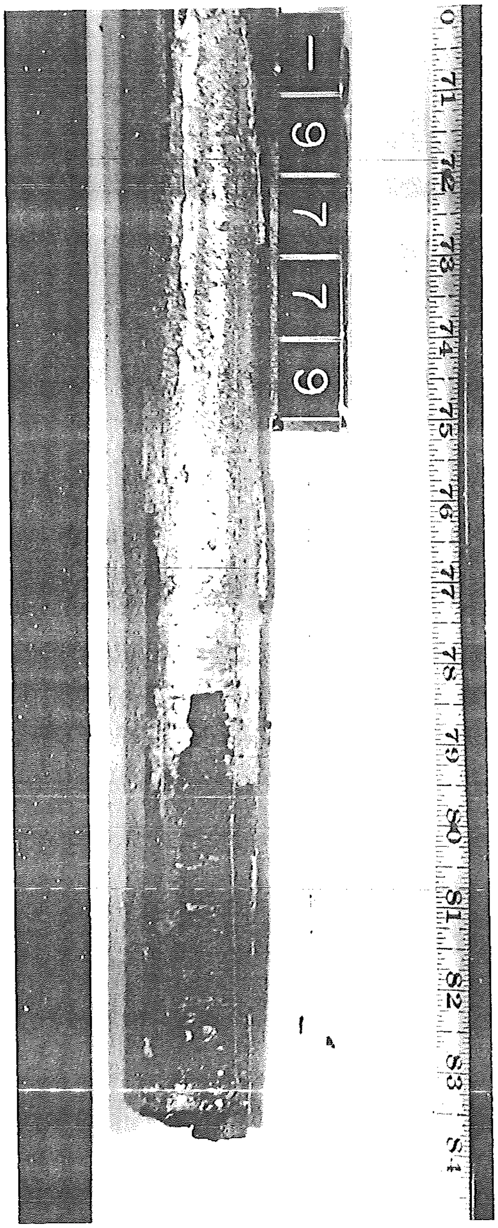

Fig. 6—Part of a normally cooled irradiated (1000 mwd/ton) rod from circle 4 (L-19). At the top the inner sheath can just be seen. Below that most of the aluminum has sloughed off, leaving a coat of aluminum-uranium alloy on the rod. Lower still, where the heat was greater, the uranium appears oxidized, but the aluminum is still present in the surface layer.

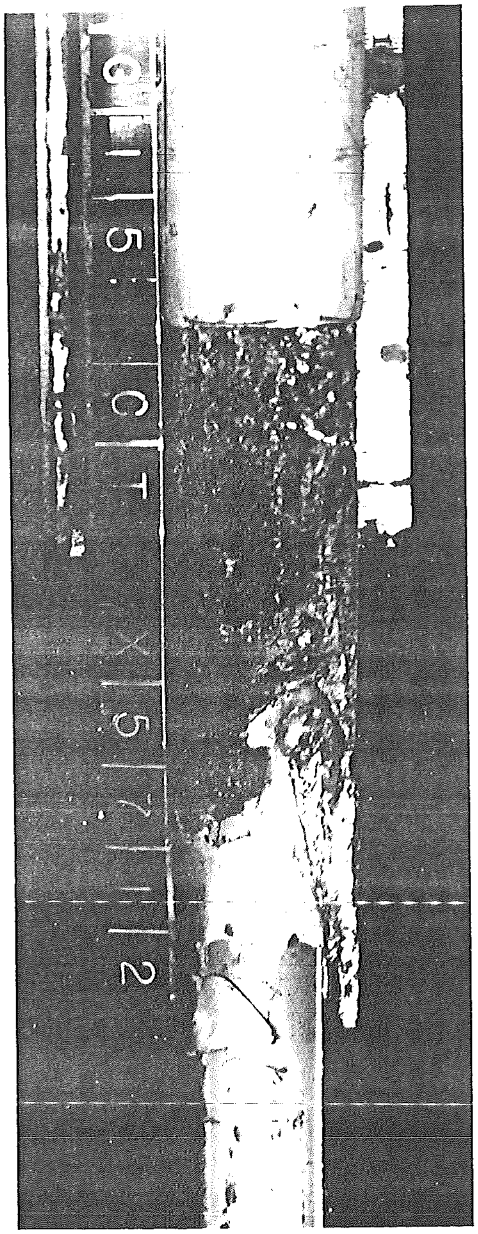

Fig. 7—Lower part of the air-cooled rod from G-15. Starting at the bottom is undamaged inner sheath, then melted and crumpled aluminum. Above that is a dark mass, apparently uranium and uranium oxide, which molded itself into the calandria tube, a few inches of which appear at the top, the remainder having been cut away.

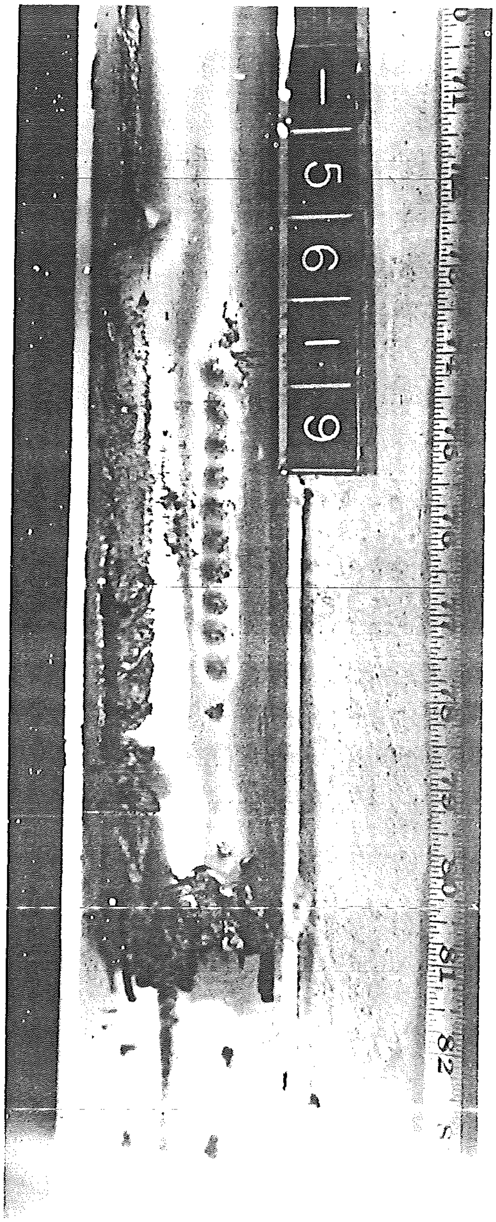

Fig. 8—The calandria tube just above the position of maximum flux in a temporarily cooled rod in circle 6 (L-9). The rod had not been previously irradiated. Evidently at the lower end only a shell remains. A dark coating covers the inside of the greatly distended calandria tube. The regularly spaced marks were made during removal to squeeze the tube back towards normal size.

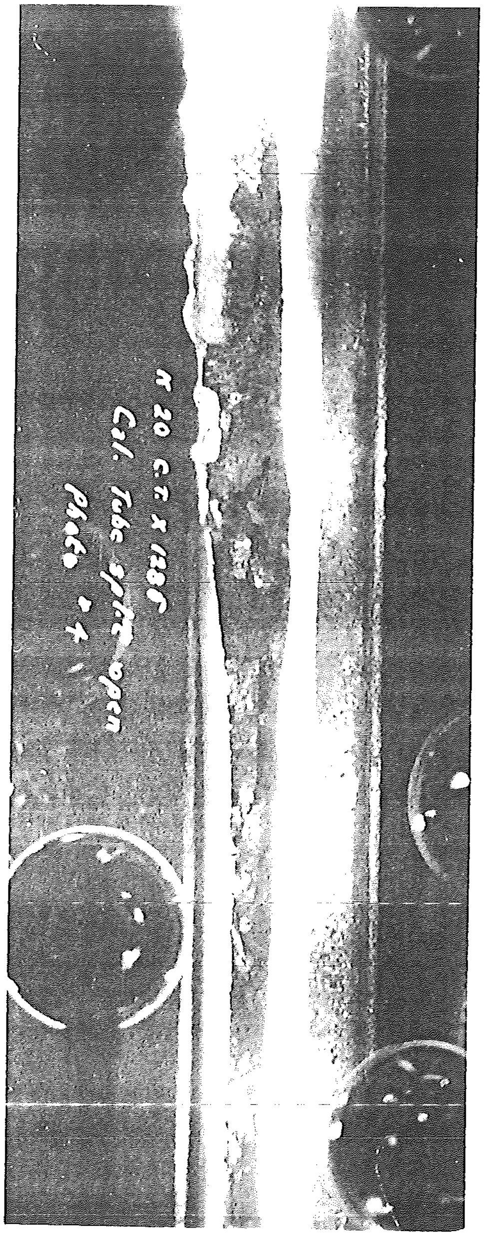

Fig. 9—Part of calandria tube K-20 above the level of maximum damage. (From circle 4, temporary cooling, center irradiation of rod 1450 mwd/ton.) The tube has been split longitudinally to reveal the contents, which bear no resemblance to the original rod assembly.

be seen. The central parts of the aluminum sheaths melted and ran down the rod, congealing between the calandria tube and the rod. This aluminum formed a barrier on top of which molten uranium formed an ingot contained by the calandria tube (Fig. 7), heat transfer between the calandria tube and heavy water apparently being sufficient to preserve the calandria tube. From this, one can deduce that in the cases where damage was extensive the light water played a big part in determining the type of damage. First of all, steam under pressure in the rods was the cause of the initial rupturing of the outer sheaths. In some cases, e.g., M-14 (Fig. 4) , flying chips from this rupture may have ruptured the calandria tube; but more important perhaps, in most cases, the reactions between uranium and either steam or water were the direct cause of the damage to the calandria tubes. The appearance of the residual metal in some of the worst cases can be accounted for only by considerable chemical reaction, not merely by melting of the materials. Whether or not the highly exothermic aluminum water reaction also had a significant role cannot be decided. It seems unlikely, but conditions may have been suitable in very restricted regions for the inner sheaths to react.

The heat required as a short pulse to promote explosive reaction between a uranium or aluminum wire and water has been stated[6] as about 0.05 cal/mg, but this estimate is probably low. The maximum energy density in the uranium during the accident was 0.125 cal/mg. Because the power increased relatively slowly, the cooling would have removed a large part of this. Once the melted uranium came into contact with bulk water, chemical reaction would be quenched. Some of the uranium removed from the bottom of the calandria had the appearance of having been melted and then cooled.

Several cases in circles 4 and 5 of major damage to the central portion of temporarily cooled rods were accompanied by small punctures in the outer sheath and calandria tube at a level about halfway between the top of the heavy water and the top of the calandria. These look like pressure punctures and are associated with marks of a blast of hot gas. At this level where the calandria tube is not cooled by heavy water, both the tube and outer sheath may have become unduly hot when steam forced out the water and may have given way because of reduced strength at high temperatures.

It appears that irradiated rods are more liable to damage than are fresh rods. This is shown very clearly in circle 3 and to some extent in circle 4. The reason is not clear. The difference between the initial temperatures of fresh and irradiated rods would be too small to account for the effect. The thermal conductivity of uranium may be reduced by irradiation, leading to higher internal temperatures during the power surge. Another, and possibly a more likely cause of the greater fragility, is the mechanical deformation produced by irradiation. This reduces the size of the cooling channel and sets up stress in the inner sheath, both of which predispose to failure.

8. POWER LEVEL AND TEMPERATURES

The records of the ionization instruments were used to give the shape of the power curve (Fig. 5 in reference 1), but, because of the unknown pattern of shut-off rods and its effect on the indications from ion chambers in the graphite reflector, the absolute magnitudes were suspect. An early estimate of the total energy released was based on the temperature rise of the heavy water. On account of heat from chemical reactions and difficulties in estimating the temperature rise, this resulted in a very gross overestimate. The best measurements of the energy have been obtained by radiochemical analysis of uranium wafers cut from previously unirradiated rods. Both plutonium and fission-product content were determined and led to an energy release of 2000 megawatt sec. This puts the peak power at 80 megawatts, as compared with 60 to 90 megawatts deduced from the normal calibration of the ionization instrument. In the calculation of total energy from the radiochemical analyses, the normal flux distribution was assumed. The agreement between these values of peak power shows that flux distortion and shadowing were not very large.

Metallographic studies of uranium disks cut from rods at J-11, K-16, and L-9, which had been prepared in the alpha phase and which had not previously been in the reactor, clearly showed circles of recrystallization concentric with the rod. The circle encloses the region whose temperature exceeded the beta transition. Thus some points of the 668°C temperature contour have been obtained. The excursion into the beta phase did no apparent damage.

In some rods the upper portions were hollow, the hole being conical and tapering toward the top. Evidently the uranium had melted and run out, the taper being due to the decrease of flux and the lower water temperature toward the top of the rod. Other rods, although not empty, had a similar central cone filled with uranium oxide.

A number of instances occurred of a behavior seen in a previous failure. This is the formation on the uranium of a protective coating of aluminum alloy when the aluminum sheath has melted. The alloy extends from the aluminum melting zone but disappears where the temperature has been much higher (Fig. 6).

9. INCIDENTAL INVESTIGATIONS

The accident posed many questions, some of which have been discussed, and provided material for future study. Several undamaged calandria tubes were taken out and preserved. The calandria itself was arranged in the disposal area so that access can be had at the top, and the effect of the long irradiation at high power will be investigated. The variation of activation through the thermal shield is presently being measured.

An investigation of leaching of fission products from uranium hydride and oxide was undertaken for comparison with the fission-product distribution in the water from burst rods. Work is still in progress at the time of this writing. As was to be expected and in agreement with the observations in the basement, strontium leaches preferentially, particularly from uranium hydride.

Some small-scale experiments were carried out to find the behavior of hot uranium in contact with water. Strips of uranium of about 0.04 × 0.06 in. cross section and rods of 0.125-in. diameter were heated electrically under water. Water at 25 and 90°C was used. Both slow and fast (about 1 sec) heating was tried without any evidence of sustained violent reaction. One rod, mounted vertically, continued to glow for about 7 sec after the power was cut off. Aluminum clad wires were also tested but with very minor reaction. The results showed that once the uranium came into contact with bulk water it would be quenched. Useful information concerning uranium-water and aluminum-water reactions has since been provided by AEC.[6] Earlier experience included a case in which a bucket of uranium turnings under water was ignited by a burning uranium chip. This had been interpreted to mean that, after the NRX rods broke, the uranium and heavy water might have continued to react for some time. It seems likely that the mixture of turnings and water is not representative of bulk uranium and water and that the uranium must be raised well above its melting point if a violent chemical reaction is to be induced.

10. CONCLUSION

The story has now been brought to the stage of dismantling and decontamination. When the decision to change the calandria was taken (and once the extent of damage was proved by inspection of the calandria through a few of the holes in the calandria tubes the decision was easy to make), dismantling of the reactor was started to permit removal of the stuck rods and calandria.

During the early studies it was felt that possibly some new phenomena of importance to reactor technology may have been involved. This accounts for the investigations outlined in Sec. 9. Nothing has appeared to warrant belief in any such events. Unfortunately it is not possible to determine whether aluminum reacted, but comparison of the energy evolution deduced from the heavy-water temperatures with the energy deduced from radiochemistry, taking into account the obvious contribution from uranium, does not leave much margin for heat from other sources.

The runaway, while causing a major disruption in the work of the Project, was nevertheless small compared to the possible magnitude. Mechanically, a few uranium rods melted and damaged their containing tubes. The radioactive contamination has prolonged the repair enormously, but has at no time constituted an uncontrolled danger. No cases of harmful exposure have resulted. Examination suggests that a slightly greater power at an early stage might have expelled fission products in large enough amounts to have produced dire consequences locally. One more shut-off rod up or partially up could have made the difference.

Many lessons have been learned that are of use in reactor design. This applies especially to planning for possible decontamination, and such ideas are being incorporated in the NRU reactor. The opportunity is being taken while the reactor is disassembled to improve the thermal shielding above and below the calandria with a view to increased power of operation.

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REFERENCES

1. W. B. Lewis, The Accident to the NRX Reactor on December 12, 1952 (Part I), Reactor Sci. Technol., 3(4): 9 (December 1953).
2. W. B. Lewis, The NRX Pile at Chalk River, Phys. Today, 4: 12 (November 1951).
3. F. W. Gilbert, Canadian Facilities for Isotope Production and Bombardment, Nucleonics, 10(1): 6 (1952).
4. D. G. Hurst, Chalk River NRX Nuclear Reactor, Elec. Eng., 70: 476 (1951).
5. W. J. Henderson, A. C. Johnson, and P. R. Tunnicliffe, An Investigation of Some of the Circumstances Pertinent to the Accident to the NRX Reactor of December 12, 1952, Chalk River Report NEI-26.
6. W. C. Ruebsamen, F. J. Shon, and J. B. Chrisney, Chemical Reaction between Water and Rapidly Heated Metals, Report NAA-SR-197.

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