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THE ACCIDENT TO THE NRX REACTOR ON DECEMBER 12, 1952

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ABSTRACT

Because of a complex concurrence of mechanical defects in the shut-off-rod system and operating errors which alone would not have caused serious trouble, a power surge occurred in the NRX reactor during preparations for experiments at low power. Some of the cooling arrangements at the time were adequate only for low-power operation. Consequently some of the natural-uranium metal melted and ruptured the aluminum sheathing and tubes which separated the heavy-water, air, and cooling-water systems. As a result some 10,000 curies of fission products from long-irradiated uranium were carried by a flood of 1,000,000 gal of cooling water into the basement. Fused masses of highly irradiated uranium and uranium oxide were left inside the calandria, and the core vessel of the reactor and tubes of the calandria were severely damaged.

In such a high-flux reactor where the transient xenon poison may affect the reactivity by 40 milli-k (mk), the shut-off rods have to cover a reactivity range of about 70 mk. As one lesson from the accident it appears preferable to withdraw the first or safeguard bank of shut-off rods soon after shutting down, instead of making this the first step of the actual start-up.

1. INTRODUCTION

On Friday afternoon, Dec. 12, 1952, in a normal but not quite routine operation, the NRX 30-megawatt heavy-water research reactor at Chalk River was severely damaged owing to a concurrence of mechanical defects and operating errors. It is very easy to prescribe measures to prevent any recurrence of the accident, but it has to be remembered that this reactor has been characterized as having 900 devices for shutting it down but only one for starting it up. Adding a few more safety devices might prove to be the last straw in preventing operation, or it might make the operators' work so involved that some quite different accident would be provoked. Setting aside the simple self-evident lessons, there are some more subtle considerations which may be of value for future reactor designs and therefore give this article some interest beyond that assured by human emotions to all reporters of major misfortunes.

What occurred, in brief, was that, during preparations for reactivity measurements, the reactor was unexpectedly found to be divergent, and at the same time there was some mechanical defect preventing shut-off rods from dropping in. Even this would not have had serious results if a number of the uranium rods had not at the time a purposely reduced flow of cooling water. As the reactor was leveling off in power at about 17 megawatts, the cooling water of these rods boiled, thereby increasing the reactivity and the power. At the increased power, some of the aluminum sheathing the uranium melted. At least one rod blew itself apart, and molten uranium poured out from the core of the upper part. Some of the tubes retaining the heavy water ruptured. All the fluid systems of cooling water, air, heavy water, and helium were then in contact. The cooling water being under the highest pressure was forced in, displacing air and helium, and helped to bring the reactor below critical. Meanwhile, however, the operators had been forced to their last resort; namely, to open valves which dumped the heavy water rapidly to storage tanks below. Within 60 sec the power was back to zero, but major problems of radioactive contamination had been set.

In the absence of radioactivity the damage would have been simple though tedious to repair, but the presence of large amounts of intensely irradiated exposed uranium in very inaccessible places presented a cleanup problem on a scale without precedent. There were many kilograms of uranium exposed as metal or oxide containing over 3 kg/ton of fission products in the ruptured interior of a reactor which was not designed to be repairable. Months later this material would still have a radioactivity of about 1 curie/g.

At the time of writing the reactor had been stripped of all significant amounts of uranium; and the calandria, the aluminum vessel at the core of the reactor, had been removed so that a new one could be installed. Considerable problems of decontamination remained in the basement regions below the reactor, but the worst difficulties of excessive radiation hazard had been successfully passed.

Following an explanation of relevant features of the design of the reactor, a more detailed account of the operating sequence of events will be given, together with indications of some lessons to be learned for the future. A second article will discuss the nature of the damage and attempt to reconstruct the sequence of events inside the reactor system. Further information is given in references 1 to 7.

2. CONTROL SYSTEM OF NRX REACTOR

The normal sequence of operations to start up the reactor is (1) to set the level of the heavy water at a predetermined level somewhat below that required for criticality; (2) to raise the shut-off rods; (3) to raise the one control rod which gives only a fine control equivalent to about 10 cm height of heavy water; and finally (4) to raise the level of the heavy water slowly to that predicted for criticality.

The shut-off rods are thin steel tubes filled with boron carbide designed to be as light as possible in weight. The rods are light to permit rapid acceleration and deceleration in being driven into position (a 10-ft travel) by air pressure. The piston at the head of the rod is 17 in. long and has to be heavy to provide radiation shielding. The total weight of the moving parts (rod and piston) is 29 lb.

The air pressures are manipulated by electrical controls. In addition, the piston heads in the up position are held by a solenoid magnet. The presence of each rod in a fully up position is indicated by a red light on the control desk.

There were 12 shut-off rods, and the basis of their operation was that 7 in the down position were sufficient to hold the reactivity of the reactor below critical for any approved charge of fuel and load. Actually all are not equal in effect because of their differing positions in the reactor. On release from the solenoids the rods are normally given an initial acceleration by 100 psi air pressure on the piston, overcoming 13 psi upward-flowing cooling air. The rods would normally also drop under gravity alone against this upward air. With air-pressure drive the rods are halfway down in $\frac{1}{3}$ to $\frac{1}{2}$ sec after the trip signal; without head air pressure they take 3 to 5 sec to drop all the way.

The 12 rods were electrically interconnected in the following "banks" or groups which operated together:

Bank No.	No. of rods
1	4
2	3
3	2
4	1
5	1
6	1

Bank 1 was brought up by push button 1 at the control desk. The remainder were brought up in the sequence of the bank numbers by automatic interconnection after pressing push button 2.

It may be noted that the bank brought up by push button 1 has to satisfy different conditions from those responding to push button 2. To stress this difference, the term "safeguard bank" is applied to bank 1. As explained later the number of rods in the safeguard bank was by design 1 greater than that in any other bank; therefore, since the number chosen was 4, no other bank might contain more than 3. Moreover the 3 least effective in the safeguard bank had to be more effective than the total in any other bank.

The safeguard bank was to be brought up only from a condition in which all the shut-off rods of the other banks were down. This had been effected by a safety circuit involving "limit" switches operated by each rod when fully down. Owing, however, to defects in these switches and their being subject to flooding which could make them a hazard, this "safety" circuit was not in operation at the time of the incident. The added responsibility was accepted by the operating supervisor.

The other shut-off rods satisfied the different condition that none could be raised by the electrical controls unless the rods of the safeguard bank were all fully up and their headgears charged to 80 psi air pressure. As appears later, however, there existed other means of getting them up.

The design reason distinguishing the safeguard bank is that, for safety, no shut-off rod may be raised unless either (a) more than 7 shut-off rods would be left fully down, or (b) more rods are available for quick release than are being raised at any time. To make start-up possible, some rods must satisfy condition (a) and not (b), and, if the total of shut-off rods is only 12, no more than 4 may be set for condition (a). All other rods must satisfy condition (b). To achieve a safe start-up in the shortest time, as large a number as possible and the most highly effective rods were in the safeguard bank. The reason for allowing always one more than the minimum safe number is to allow for one undetected failure in the safety system.

It may be worth noting that in a high-flux reactor, such as NRX, the range of reactivity caused by the transient Xe^{135} poison is over 4 per cent or in more convenient units 40 milli-k (mk). The maximum reactivity available might be 10 mk less than required to overcome the peak poison. The shut-off-rod system had not only to cover this range of 30 mk between the reactivity available to overcome the transient poison and that required for the unpoisoned reactor but also that which might result from loss of the cooling water from the system (estimated as 25 mk). Cooling the reactor from its normal operating power adds another 5 mk. The 12 shut-off rods commanded a total of 70 mk. To avoid being poisoned out after a shutdown from high power, it was designed that the reactor could be started up in about 10 min, requiring a mean rate of removal of shut-off rods of 7 mk/min. Actually this was unevenly spread in time, and the first 4 shut-off rods commanding 30 mk were arranged to be withdrawn together in an operation which would be completed in about 45 sec, although the actual withdrawal might take place in a few seconds. This rapid rate of withdrawal has been subject to criticism, and it may therefore be of interest to note that, in the reactor as originally designed and operated, the shut-off rods commanded a higher reactivity and were withdrawn in a shorter time. It is important to understand the force of the arguments on both sides leading to the compromise. In a very high-flux thermal reactor which is subject to incidental trips, safety must be assured by measures other than a very slow maximum rate of withdrawing control rods.

To understand the course of events there is also a practical detail of the shut-off-rod system which has to be appreciated. This concerns the functions and location of four push buttons at the control desk.

Push button 4 is mounted on a wall panel at the left of the desk. It serves to charge air to the heads of the shut-off-rod assemblies. The release of this air drives the rods down.

Push buttons 1, 2, and 3 are on the panel shown in Fig. 1, centrally mounted on the control desk.

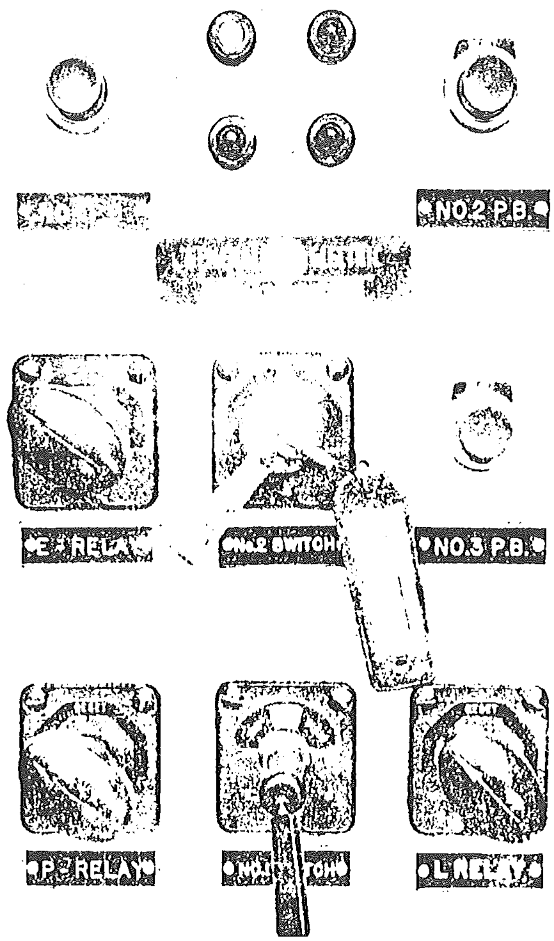

Fig. 1—Central panel on control desk.

Push button 3 serves to increase temporarily the current through all solenoid magnets in the shut-off-rod head system. This ensures good seating of the air-release valves and also draws the pistons on the shut-off rods fully home. The normal maintained current is adequate to hold the rods and valves in position. Excess current above the minimum would delay release.

As already mentioned push button 1 raises the safeguard bank of shut-off rods, and push button 2 raises the remaining banks in automatic sequence.

To ensure satisfactory operation, push button 3 is pressed in conjunction with push buttons 4, 1, and 2. If it is not pressed with push button 4, air may leak from the head system; if it is not pressed with 1 and 2, the shut-off rods may not be drawn fully home, and safety circuits would prevent the start-up operation from proceeding further.

3. EMERGENCY PROCEDURE

Since the events led to following the prescribed emergency procedures, it should be noted that these procedures had been set up and summaries were posted in various positions throughout the plant and laboratories and included as a full page in every copy of the project telephone directory. A copy of the procedures is reproduced as Fig. 2. The procedures are designed especially for situations in which large amounts of radioactive material may be spilled or dispersed in the atmosphere and have the dual objective of safeguarding health directly and indirectly by limiting the spread of radioactive contamination particularly in areas where cleanup is difficult yet necessary.

4. ORGANIZATION

A number of the senior staff were absent from Chalk River at the time of the incident. The organization of those present and directly concerned is conveniently represented as shown in Fig. 3.

5. REACTOR LOADING AND INTENDED OPERATION

The experiment on hand was a series of measurements of the reactor reactivity at low power. The main object was to compare the reactivity of long-irradiated rods with that of fresh rods. To avoid complications from dimensional changes in the water-cooling channels, it was necessary to blow the water out of some rods and substitute air cooling. At the time of the incident only one rod was air-cooled and that was a fresh unirradiated rod.

EMERGENCY SIGNALS

STAY-IN — RISING and FALLING SIGNAL — Emergency Sirens

NOTE: Stay-in procedures will be carried out from time to time as drills.

EVACUATION — CONTINUOUS SIGNAL — Emergency Sirens

Think of others! Are they all out?

ALL CLEAR — SERIES of INTERMITTENT BLASTS — Plant Whistle

EMERGENCY PROCEDURE

1. A special procedure, No. 8-2-1, outlines the action to be taken when an emergency arises which may subject the whole plant or a large section of it to a hazardous condition which cannot be controlled by normal methods. A typical condition of this nature would be the release or spread of radioactive contamination in large amounts. The following summarizes the procedures and action to be taken in such an event by members of the staff.

2. Anyone who detects or suspects such an emergency condition shall immediately notify his supervisor. The latter, if he agrees that an emergency exists, shall report the location, nature of the emergency and help required, to the Shift Supervisor, Pile Branch, Phone 422, Building 100. If your supervisor is not readily available, report to Phone 422 yourself.

3. Types of Emergencies

   (a) STAY-IN - Emergencies in which it is deemed advisable that all persons, except those instructed otherwise, shall remain or proceed indoors.

   (b) EVACUATION - Emergencies in which all persons, except those specifically designated to remain, shall leave the plant.

4. Signals

   (a) STAY-IN - A rising and falling signal on the emergency sirens.

   (b) EVACUATION - A continuous signal on the emergency sirens.

   (c) ALL-CLEAR - A series of intermittent blasts on the plant whistle extending for three minutes.

   (d) TEST - The sirens will be tested on the 4th Sunday of every month at 1400 hours, local time.

5. Action on Stay-In

   (a) Proceed to nearest building and remain there until instructed otherwise.
   (b) Close all windows and doors and take such special action as has been laid down for the building.
   (c) Proceed with normal work as far as possible.
   (d) Do not use the telephone.

6. Action on Evacuation

   (a) Make all offices and laboratories safe, and lock up all secret documents, etc.
   (b) Walk quickly to the gate, holding a handkerchief over mouth and nose.

7. Certain persons, such as building heads and all Branch heads, will have been given special instructions to carry out in the event of an emergency. If you are one of these, familiarize yourself with your duties.

Fig. 2 — Emergency procedures.

All enriched fuel rods, adjuster (cobalt load) rods, special assemblies, and isotope loads were out of the reactor except one thorium and uranium sample rod in an outer region.

A full complement of normal uranium rods was in position. Certain of these rods were to be moved between measurements and had only temporary cooling by means of hoses. Such cooling is adequate for low-power operations.

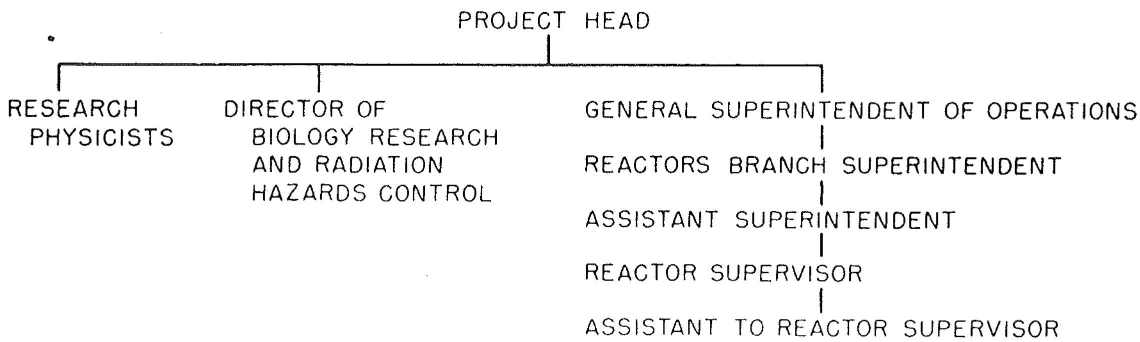

Fig. 3—Organizational chart of personnel on duty and responsible for operation of the reactor at the time of the incident.

As the reactor had not been up to power for several days, transient poison had decayed, a necessary condition for the experiment.

The heavy-water level was at 260 cm and was to be raised to 277 cm for the planned experiment. The reactivity changes by about 1 mk for 3 cm change of heavy-water level in this range.

Because of the experiments in hand, research physicists were present in the reactor control room, but the reactor was operated by the reactors branch personnel who alone have authority for this. The reactor loading to be used was recommended by the physicists and approved in writing by the reactors branch superintendent.

6. DESCRIPTION OF THE INCIDENT

The immediate chain of events which led to the accident began with an error by an operator in the basement who opened by mistake three or four bypass valves on the shut-off-rod air system, thereby causing three or more shut-off rods to rise when the reactor was shutdown. The supervisor at the control desk noticed this because the red lights came on. He phoned to the operator in the basement to stop and went down himself to investigate and rectify the situation, leaving his assistant at the control desk.

He recognized the operator's mistake and was horrified at the possible consequences if the operator had continued to open these wrong valves (actually he could not have opened all valves since some handles had been removed for safety). The supervisor rectified all valves and checked air pressures. He assumed that all shut-off rods would drop back into position, but, on account of unexplained mechanical defects, it is apparent from subsequent events and inspection that two or three did not drop back, although they slipped down sufficiently to clear all the red lights on the control desk.

The supervisor then phoned his assistant to press buttons 4 and 1. He had intended to say 4 and 3, but under normal circumstances 4 and 1 should have been safe (all the shut-off-rod red lights were out). His assistant therefore did so. Having to leave the phone to reach simultaneously with two hands the two buttons, he could not be recalled to correct the mistake. Button 3 not having been pressed, the air pressure brought up by button 4 leaked away.

Up in the control room it was soon evident when the first bank of shut-off rods was raised by button 1 that the reactor was above critical, which was of course a complete surprise.

It takes a few seconds for this to be apparent. There was surprise but no alarm for the next step would be to trip the reactor and thus drop back the shut-off rods. This the assistant did about 20 sec after pushing button 1. But two of the red lights stayed on, and in fact only one of the four rods of the first bank dropped back into the reactor and that over a period of about $1\frac{1}{2}$ min. Even though, as it appeared, the air pressure had leaked from the header, all shut-off rods should have nevertheless dropped back under gravity.

The galvanometer spot indicated that the power level was still climbing up. The assistant telephoned the supervisor in the basement urging him to do something to the air pressure to get the rods down.

Others in the control room were worried: the physicists, the assistant superintendent of the reactors branch, and a junior supervisor. At least two thought of the last resort; namely, to "dump the polymer." All were familiar with the process as it had been done the previous day for experimental purposes. The assistant superintendent gave the word; one of the physicists was already reaching for the dump switch and beat the others to it.

However by this time the reactor power was up in the tens of megawatts, and the dumping took a few seconds to become effective. Then a fear arose that they might be dumping too fast as the helium pressure had dropped back sharply, and they envisaged danger of collapsing the calandria by vacuum. The assistant superintendent halted the dumping after about 1 min but after a little thought resumed it. However, in 10 to 30 sec after starting to dump, the instruments were back on scale, and the power rapidly dropped to zero. The assistant superintendent went to report to the superintendent, but the consequences were only beginning.

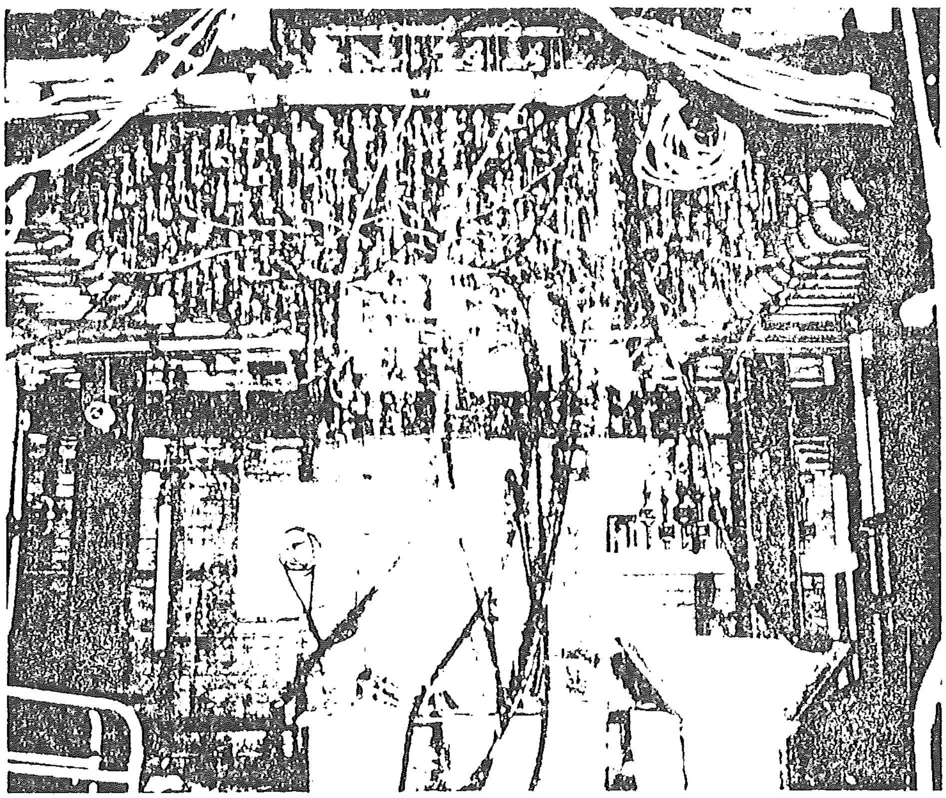

Fig. 4—Lower header room below reactor after the accident with water gushing down.

In the basement the door into the chamber under the reactor (the lower header room) was open. Through this an operator saw water gushing down (Fig. 4), and immediately he called the supervisor. Their instant reaction was to suspect any water as being heavy water; therefore the supervisor and operator rushed in with a bucket and collected a sample, which was soon found to be light water but radioactive.

The assistant superintendent, returning to the control room, was met by an operator who reported a rumble and a spurt of water up through the top of the reactor.

Then the air activity began, and automatic radiation-level alarms sounded in the reactor building. A phone call to the control room from the adjoining chemical extraction plant reported atmospheric activity off-scale and requested the emergency stay-in procedure. The sirens for this were sounded. The radiation hazards control branch got busy reading instruments, making surveys, and collecting reports. Some minutes later the activity inside buildings with forced ventilation was found higher than outside; therefore on the advice of the Biology and Radiation Hazards Control Director the Project Head gave the order for the plant evacuation procedure, and that went into effect.

Meanwhile in the reactor system not earlier than 30 sec before the dumping began, helium began to leak at a rate of 140 cu ft/min. After $3^{1}/_{4}$ min, by which time the reactor power had been down to a negligible level for 2 min, the reserve gasholder was almost empty. Then suddenly in less than 30 sec the 585 cu ft gasholder rose to its fullest extent. The change of direction of motion of the gasholder was so abrupt on the record and its motion so well-timed by pen marks at 15-sec intervals that it can be deduced with certainty that within a period of 15 sec the gasholder became connected presumably to a mass of gas at high enough pressure to give a large acceleration to the massive gasholder. Further discussion of this will be given in the second article.

About the same time that the gasholder was forced up, the radiation level in the reactor building became high. Respirators were issued to those in the control room. All not concerned with the reactor operation were evacuated from the building.

Holding discussions in gas masks is difficult so after a few further minutes those concerned with reactor operation also went to an adjacent building and planned further steps, returning to the reactor building to put them into effect.

7. TIME RECORD SUMMARY

The time of pressing push button 1 will be taken as 1507 hr. Times are in most cases very approximate, and certain discrepancies are known to remain. The sequence of events is indicated in Table 1.

8. THE POWER SURGE

Although all relevant instruments went off scale, it proved possible to piece together data to construct reasonably well-timed curves of power and reactivity. This reconstruction is described by W. J. Henderson, A. C. Johnson, and P. R. Tunnicliffe in Report NEI-26, and a summary of their conclusions is given here.

Before the first bank of shut-off rods was raised the reactor was more reactive than supposed owing to a number of shut-off rods not being down. This unsuspected extra reactivity was about 10 mk. Raising the first bank made the reactor overcritical by about 6 mk, and it diverged with a doubling time of about 2 sec, reaching a power of the order of 100 kw. At this point the reactor trip circuit opened, but only one shut-off rod fell slowly in. The reactor continued to diverge but at a rate decreasing with time in such a way as to suggest that it would have leveled off at about 20 megawatts. (The scale for power is nominal owing to unknown shadowing effects by shut-off rods on the ion chambers.) At 17 megawatts on this scale boiling is presumed to have occurred in some of the temporarily cooled rods, expelling light water from the reactor and increasing the reactivity by at least 2 mk. The reactor continued to diverge for a period of 10 to 15 sec and reached a power between 60 and 90 megawatts when it was checked by opening the heavy-water dump valves and also possibly by ingress of light water through ruptures in the cooling-water tubes.

The reactor power was greater than 1 megawatt for less than 62 sec.

It is to be noted that the powers in the megawatt range quoted here are from a Leeds and Northrup Micromax recorder (1 ma full scale) operated from an ion chamber and amplifier. The full-scale deflection normally corresponds to a reactor power of 60 megawatts. The transient was too rapid to record properly, but examination of the trace showed that the stationary positions of the pen during successive tentative balances by the instrument could be readily distinguished. Since the time intervals between successive balance attempts are well defined, a good graph could be made of instrument reading against time. This is shown in Fig. 5.

The recorder and its amplifier were removed and set up to operate from an electronic reactor simulator. The response of the amplifier to transient input signals showed that the limiting time constant lay in the recorder. The output from the simulator was therefore fed directly to the recorder. The chart speed was increased to 3 in./min. In order to estimate the reactivity increase which occurred at 17 megawatts, the simulator was leveled off at this power and then the reactivity was increased by a known amount and the "reactor" allowed to diverge. For an excess reactivity of 2.5 mk or greater, the recorder ran at its maximum rate. The estimate that the reactor power did not exceed 90 megawatts (on the scale of this instrument) is based on the observation that a sufficient overload signal would jam the indicating galvanometer and the recorder would remain at full-scale deflection. This did not occur in the incident as shown by Fig. 5.

Confirmation of the maximum power reached

Table 1—Approximate Time Sequence of Various Phases of the Incident

Time	Activity or condition noted
1507 + 00 sec	Push button 1 pressed
1507 + 20 sec	Manual trip operated
1507 + 30 sec	Power ~ 17 megawatts; reactivity suddenly increased by 2.5 mk; helium leak started
1507 + 44 sec	Dump started
1507 + 49 sec	Power ~ 100 megawatts; instruments indicating activity of air passing to the stack off scale
1508 + 08 sec	Low power restored
1509	Radiation level by Cutie Pie 40 mr/hr generally around control room and 90 mr/hr at door leading to top of reactor
1510	200 mr/hr at top of reactor
1511	Gasholder rose suddenly
1511	900 mr/hr on bridge at top of reactor near door of control room
1512	Circulating pumps and constant-level pump turned off
1515	Wearing respirators advised
1517	Stay-in emergency signal given
1517	Ventilating air to reactor building turned off
1527	5 r/hr in auxiliary equipment room (basement) near north wall by pencil chambers; similar radioactivity at door of lower header room
1537	Air-filter sample in radiation hazards control room (1.4 m^3) gave >20,000 counts/min
1537	Electric fans added to steam fan extracting air from reactor; radiation level around steam fan 900 mr/hr
1537	Level in heavy-water storage tanks rose so dump valves again closed; water level in calandria rose to 134 cm and remained so
1520 to 1545	Air-filter samples taken outside plant area ~ 500 counts/min $\beta\gamma$ from 3 to 4 m^3
1547	Plant evacuation signal given
1615	Air-filter sample in Building 300 adjacent to reactor showed no detectable activity
1640	Weir box raised to top of calandria to prevent light water entering storage tanks by way of the weir box overflow line
1700	Air-filter sample outside (5 m^3) showed nothing detectable above background of 1000 counts/min
1800	Flood water at foot of steps to auxiliary equipment room in basement highly active
2045	Air-filter sample main reactor floor (14 m^3) gave 20 mr/hr on Tracerlab SUIB instrument, but no alpha activity was detectable

and an estimate of the integrated power surge is being sought from analysis of activities in fresh uranium metal in the reactor at the time of the incident. Tentatively the power surge is taken as 4000 megawatt-sec.

supposed to come from the air-cooled rod, it would require the escape of the products from 30 kg of natural uranium at the center of the rod. Much less than this is likely to have been involved because there would have been a con-

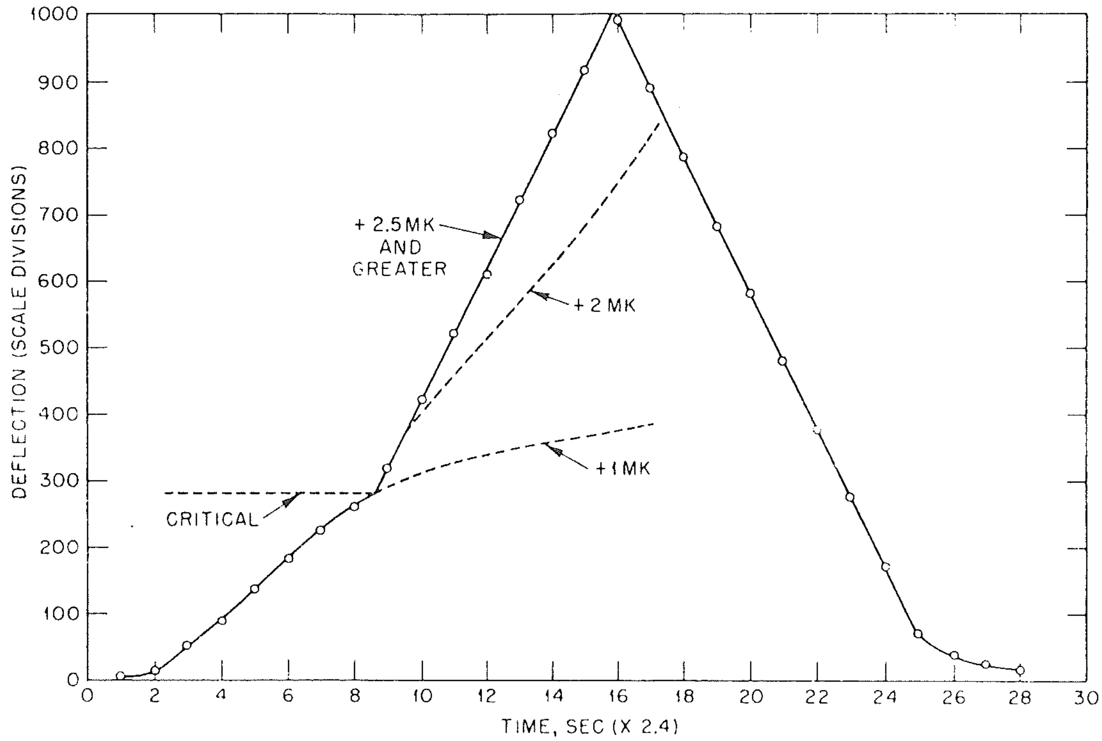

Fig. 5—Expanded trace of power recorder during the power surge with transients from simulator superposed. (Time scale is in units of 2.4 sec., the interval between successive balancings.) ——, NRX transient. - - -, reactor simulator transient.

9. EARLY OBSERVATIONS AND DEDUCTIONS

The activity discharged by the air through the stack behaved like fission products from a very short irradiation and is attributed to the escape of volatile and gaseous fission products from the uranium with ruptured sheathing together with most of the fission products from the melting, fracture, and rapid oxidation of the uranium of the air-cooled rod of previously unirradiated uranium.

The best estimate which it has been possible to make is that the total fissions involved would be 10^{18}, and, assuming the power surge was 4000 megawatt-sec, if all the activity were

siderable escape of volatile and gaseous fission products from other ruptures.

The estimate is that of Drs. W. G. Cross and S. A. Kushneriuk based on the exposure of 350 mr on a film worn by an electrician up a pole adjacent to the reactor stack at the time.

It was not considered safe to stop the flow of water to the basement since the condition of the uranium was not known. It was feared that, since some of the metal had been so highly irradiated (about 3000 mwd/ton), it would heat itself up, oxidize rapidly, and might even catch fire if not cooled. The flow of water was cut back as low as considered sufficient to reach all the uranium. This flow was about 70 gal/min. It was not discharged to the river but was pumped from the basement to a storage tank. The total water collected amounted to about 1,000,000 gal and contained about 10,000 curies of long-lived fission products. This water was successfully disposed of by pumping it through a $1^{1}/_{4}$-mile pipeline to a trench system in a disposal ground where it was allowed to seep away. A check was kept on activity in water draining from this area, but no detectable activity was found even in the creek draining the area to a small lake.

10. IMMEDIATE CONCLUSIONS

Since none of the operating errors made appears to be outside the normal range of human error and since design and management aimed at setting conditions which would be safe despite normal human errors and mechanical faults, it appears necessary to take note of improvements which may be possible in all respects.

To reduce the risk of human error and mechanical failure, no doubt a better system of review and inspection should be established. This should relate the design considerations to the current practice.

In the design of a shut-off-rod system an interesting point emerges, namely, that it may be safer to plan and set experiments or normal operations with the safeguard bank raised out of the reactor. If the safeguard bank had been out when the operator in the basement made his initial mistake and blew up extra shut-off rods, the reactor would then have become critical, but the consequent dropping in of the safeguard bank would have averted any serious accident, even if the serviceability of the safeguard bank was as low as it subsequently proved to be. Moreover all would have been alerted to the hazardous condition that rods had not dropped back.

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ABOUT THE AUTHOR

W. Bennett Lewis, C.B.E., F.R.S., is Vice-President, Research and Development, of the Atomic Energy of Canada Limited, Chalk River, Ontario. He was born in England in 1908 and took the Natural Science Tripos at Cambridge in physics in 1930. He studied fine structure and energies of alpha-ray groups with Lord Rutherford at Cavendish Laboratory and received the Ph.D. degree in 1934. Dr. Lewis continued research at Cavendish Laboratory as University Demonstrator and Lecturer, working with Sir John D. Cockcroft on nuclear disintegrations by particles accelerated by high voltages and then in the construction and operation of the Cambridge cyclotron. He is the author of "Electrical Counting," published in 1942. In 1939 he was loaned to the Air Ministry for radar work and continued in this at Telecommunications Research Establishment until September 1946, serving as Chief Superintendent from 1945 to 1946. In 1946 Dr. Lewis succeeded Sir John D. Cockcroft as Director of Research at Chalk River.