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November 27, 1989

MEMORANDUM TO FILE

FROM: M. S. BRINN, R. L. MENEGUS, J. S. NEILL, H. F. RING

INCIDENTS THAT REQUIRE
EMERGENCY OPERATING PROCEDURES

All foreseeable emergencies are adequately forestalled by installing in the reactor areas of the Savannah River Plant a number of pieces of auxiliary equipment. This precaution is taken in order to prevent permanent damage to the main equipment and to contain the radioactive material in the restricted areas of the plant.

However, in the unlikely event of failure* of some pieces of the main and/or auxiliary equipment, it is necessary that the operators take coordinated emergency action in order to prevent damage and hazard. In some cases swift action is called for.

* In this memorandum failure of electrical equipment may be the result of by-passing as well as of actual physical failure.

Classification Cancelled/Changed

TO **UNCLASSIFIED**

By Authority of

1. M. S. Brinn Director 12/19/89
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MASTER

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Because there are many pieces of equipment, all of which can conceivably be said to be subject to failure or faulty operation, one could postulate an astronomical number of failure incidents, each one different. But many of these would be highly improbable or call for the same emergency action. On the master incident sheet, Table I, there are defined twenty such incidents, which represent a fair cross section of the possibilities. In compiling this table, we have kept in mind all of the worst reactor accidents that have occurred in the U.S.A. and Canada and those minor equipment failures that have occurred at SRP before the startup of the reactors. In addition, there are one or two in the table that are almost impossible to conceive in any reasonable frame of probability; these represent limiting cases insofar as hazard is concerned.

The consequences of the incidents mentioned in Table I are the results to be expected if the unaffected equipment functions properly, but the operators take no emergency action. For those cases in which damage is to be expected, emergency action by the operators can greatly reduce or eliminate entirely the damage and spread of radioactivity.

As a means of showing what actions are necessary and how rapidly they must be accomplished, the twenty incidents (in which part of the equipment fails) considered in this report are analyzed in more detail on the sheets labeled "INCIDENT No. _____". In the analysis of a particular incident, it is appropriate to mention: the symptoms that operators in the control rooms observe; the normal automatic response if the unaffected equipment functions properly; the normal action taken by the operators; the normal consequences if the unaffected equipment functions properly but the operators take no emergency action (in other words, the reactor is left to its own devices); the consequences if some of the originally unaffected equipment does not function properly; and the sequence of emergency actions to be taken by the operators to eliminate the emergency.

For purposes of cross reference, the Manufacturing Department Emergency Operating Procedures (DPSOL) numbers are given on the appropriate incident sheets. Since the incidents defined on the master sheet are often the result of compound failures, or, since for each such incident several instruments might give symptoms of trouble, while, on the other hand, the emergency operating procedures define single observations of instruments or single failures, the same DPSOL number may appear on more than one incident sheet. Thus, the appearance of a DPSOL number under any given incident does not constitute a sufficient condition for exact correspondence between the incident and the Manufacturing Department Emergency Operating Procedure.

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An example will serve to explain the preceding paragraph: DPSOL 1301 is entitled "Neutron Flux - 120%". The abnormally high neutron flux reading can be a symptom of:

- 1) just one failed or improperly calibrated instrument - which is not in the least dangerous,
- 2) a nuclear runaway - which is very dangerous,
- 3) a test of the No. 1 scram circuit - which, under control, is not dangerous,
- 4) a power level 20% above normal - which, may or may not be dangerous.

Now DPSOL 1301 is found under "INCIDENT NO. 5" (it is also found under other incidents). "INCIDENT NO. 5" is an almost impossible nuclear runaway, due to outward movement of all the control rods, that could blow off the top shield and melt the fuel, if the operators did not respond soon enough. The operator response called for in the present report is to get control rods into the reactor and dump the moderator without delay. But, an operator would not take this rather drastic action simply because the one instrument reads 120% of normal neutron flux. He should rapidly appraise the situation by looking for the other symptoms mentioned in "INCIDENT NO. 5" before taking action. . . .

The appearance of "DPSOL 1301" under "INCIDENT NO. 5" means that if this type of runaway occurred the flux would rise to at least 120% of normal. Thus, in writing "DPSOL 1301", one should consider the possibility of a nuclear runaway in addition to the other possibilities, such as faulty operation of a neutron-flux instrument.

MSB/RLM/JSN/HFT:g

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INCIDENT NO. 1

The reactor is operating at 700 MW when the main motors fail. The auxiliary motors operate, and the D₂O flow decreases to 24000 GPM.

Safety rods and control rods cannot enter the reactor to stop the nuclear reaction.

SYMPTOMS

Power level does not fall for ten sec.; therefore, nuclear instruments stay level for that period of time.

Plenum pressure falls abruptly.

Reactor outlet and Q-foil outlet temperatures rise.

Flow gages on water graphic panel show falling D₂O flow.

NORMAL AUTOMATIC RESPONSE

Scrams are called for, but the safeties and controls cannot enter. Annunciator sounds.

NORMAL ACTION BY OPERATOR

Inform supervisor. Silence horn.

Must take emergency action.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

Same as "CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION".

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

D₂O begins to boil out of the annuli at t=10 sec. By t=12 sec. most of it is ejected, and the reactor begins to shut down because of the decrease in reactivity. The pressure developed in the annulus is less than 35 psig above normal, and the transient pressure in the reactor tank is about 8 psig above normal. These pressures persist for only a few seconds. When t=160 sec., there is a small possibility of melting some of the fuel in the Q-foils. The reactor tank is not endangered, and the shields will not be displaced - providing the auxiliary motors are kept operating.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

Press the D₂O "Dump" button before 10 sec. passes, after main-motor failure, providing that the power level is observed to remain about constant. If the auxiliary motors can be kept operable, there will be almost no danger to personnel for an indefinite period, even if a few of the fuel columns melt down.

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INCIDENT NO. 1 (cont'd)SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL (cont'd)

If, however, the auxiliary motors also fail, emergency H₂O cooling in the D₂O system must be started before an hour has passed. On the water graphic panel, manipulate valves to isolate as much D₂O as possible. Then flow in 4000 GPM of H₂O through the D₂O system, allowing the H₂O to collect in the sump. Start the two sump pumps to run the diluted D₂O to the catch tank. Before the catch tank fills up, it will be appropriate to decrease the H₂O flow to not less than 1000 GPM. After the catch tank fills, the water overflows and is carried off through a drainage ditch. If the actions have been swift enough, the fuel will not have melted, and this water should not be radioactive.

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INCIDENT NO. 2

In the event of large scale military attack, a total failure is possible: main and auxiliary motors fail, safety rods stick, control rods become immobile, H_2O flow stops, instrument power fails, D_2O dump valves become inoperable.

SYMPTOMS

Complete failure of all the instruments.

NORMAL AUTOMATIC RESPONSE

None possible.

NORMAL ACTION BY OPERATOR

Inform supervisor.
Must take emergency action.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

Same as "CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION".

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

As D_2O flow decreases, D_2O will boil out of the Q-foil annuli in about 10 sec. The reactor then shuts down. The afterheat of fission heats the D_2O causing boiling for about 30 hours. Meanwhile some of the fuel will have melted. The boiling will cause radioactive fission products to be liberated to the atmosphere. Inhabitants outside the plant area downwind of the reactor should be alerted.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

Following a total failure of the important equipment, the first attempt should be to resume H_2O flow into the heat exchangers. If after the H_2O flow is resumed, the auxiliary motors cannot be started, emergency H_2O cooling in the D_2O system must be started before the passage of an hour. On the water graphic panel, manipulate valves to isolate as much D_2O as possible. Then flow in 4000 GPM of H_2O through the D_2O system, allowing the H_2O to collect in the sump. Start the two sump pumps to run the diluted D_2O to the catch tank. Before the catch tank fills up, it will be appropriate to decrease the H_2O flow to not less than 1000 GPM. After the catch tank fills, the water overflows and is carried off through a drainage ditch. If the

INCIDENT NO. 2 (cont'd)

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SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL (cont'd)

actions have been swift enough, the fuel will not have melted, and this water should not be radioactive. It is perhaps wise to make this attempt to resume H_2O flow for perhaps 6 to 12 hours following the total failure.

Then, if after that time the H_2O flow cannot be resumed, the only recourse is to break a pipe line or blast an entry into the reactor within 24 hours after the failure, and bring in about 500 GPM of H_2O , either continuously or in batches, by fire truck, rail, or temporary pipe line. This water should be forced into the reactor tank as well as possible. If any water is left in the 25,000,000-gallon storage basin, it will be satisfactory to recycle that, using a fire truck or other means. With a full basin, the afterheat can be absorbed by the storage water, which evaporates, for a period of a month or so. Of course, this recycled water may be radioactive, and all personnel should be warned to take action only with the advice of the Health Physics personnel.

The action described will decrease the escape of radioactive fission products by preventing boiling in the reactor tank.

EMERGENCY OPERATING PROCEDURES

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INCIDENT NO. 3

The reactor is operating at a steady power of 700 MW. Suddenly all A.C. instrument power fails. (This accident may involve simultaneous loss of primary instrument and actuator power, since both are derived from the same bus.)

SYMPTOMS

Failure or erratic behavior of meters and recorders.

NORMAL AUTOMATIC RESPONSE

Scram II when 440 A.C. to controls is lost.
Annunciator sounds.

NORMAL ACTION BY OPERATOR

Silence annunciator.
Notify supervisor.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

Reactor shuts down without damage to itself.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

It is difficult to visualize any circumstance that would warrant continued operation with so obvious an instrument failure as that noted in the incident above. However, the stability of the reactor is such that continued operation - even without nuclear instrumentation - would produce no sudden hazardous condition.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

If Scram II is not initiated when control rod A.C. power is lost, the operator should maintain H₂O flow to the heat exchangers and D₂O circulation. In addition:

- 1) Attempt to drive in control rods.
- 2) If (1) is not possible, press "Scram" button.
- 3) If safety rods do not fall, press "Down" button on Safety Rod Panel.
- 4) If safety rods do not enter reactor, press "Dump" button to drain the moderator.

EMERGENCY OPERATING PROCEDURES

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1373
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1381
1384

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INCIDENT NO. 4

The reactor is operating at 700 MW, and its power is rising on a period of 15 sec. Suddenly all instrument power is lost. (Note that instrument power is regularly derived from the same bus as is control rod actuator power).

SYMPTOMS

No signals; or erratic signals appear on the meters and recorders.

NORMAL AUTOMATIC RESPONSE

Annunciator sounds.

Scram II when control rod A.C. fails.

Various power scrams that should fail safe at 105%, 110% and 120% or normal.

Various Q-foil temperature scrams that should fail safe.

NORMAL ACTION BY OPERATOR

Silence annunciator.

Inform supervisor.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

Reactor shuts down without damage to itself.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

A 15-second period corresponds to an excess reactivity of about 0.28% in k. With a power reactivity coefficient of -8×10^{-4} % in k, one calculates that the reactor would rise in power from 700 MW to 1050 MW before leveling off. This 50% increase in reactor power would occur in a time on the order of 5 sec, and could, conceivably result in damage to welds because of the sudden thermal shock.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

If Scram II is not initiated when control rod A.C. power fails, operator should:

- 1) Attempt to drive in control rods (the battery is assumed to be functioning)
- 2) If controls do not go in, press "Scram" button
- 3) If safeties do not drop, press "Down" button on Safety Rod Control Panel
- 4) If safeties do not go in, press "Dump" button to drain the moderator.

INCIDENT NO. 4 (cont'd)

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EMERGENCY OPERATING PROCEDURES

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INCIDENT NO. 5

The reactor is being brought to power after a scram from normal power of 700 MW. Xenon poison is at its maximum value. There is one rod in each of the 61 control rod positions. Total k held by the rods is $\sim 5\%$. When the power is about 10^{-4} MW, all controls start moving out of the reactor at 7.5 ft/min. k is introduced at a rate of 0.04%/sec.

The safety rods fail and the power to the instruments and control rod drives fails, at this crucial time, when the power level is rising.

SYMPTOMS

Before the instrument power fails, the following symptoms appear:

Level Galvanometer shows rising power.
Differential Galvanometer shows rising power if properly set.
Log n meter shows rising power.
d Log n meter shows rising power.
Log n recorder shows rising power.
Period Recorder shows decreasing period.

NORMAL AUTOMATIC RESPONSE

Control rod reversal when period < 15 sec. ($t=7$ sec)
Scram 1 when period < 2 sec. ($t=13$ sec)
Control rod reversal when power reaches 105% of normal
Scram 2 at power of 110% of normal
Scram 1 at power of 120% of normal
Annunciator sounds.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

If Scram 1 does not take place when the period < 2 sec., the power will rise rapidly to a limit set by the metal temperature coefficient. After about 22 seconds, the power reaches 1500 MW, and coolant is ejected. Approximately 20 sec. later the fuel begins to melt. It is possible that high pressures will be built up in the reactor, and the shield blown off.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

If rods move out without action by the operator,

- 1) Attempt to reverse direction of rod movement.
- 2) If there is not response to 1, press "Scram" button.
- 3) If safeties do not drop in, attempt to lower them by means of the "Down" button on the Safety Rod Panel.
- 4) If safeties do not yet go in, press "Dump" button to drain moderator.

INCIDENT NO. 5 (cont'd)

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EMERGENCY OPERATING PROCEDURES

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INCIDENT NO. 6

Loss of control rod electrical power when the reactor is being brought up to power after a scram. Xenon decays out, introducing reactivity into the reactor. Control rods jam at a position such that the rising period is 30 sec. or more (normal startup).

SYMPTOMS

Rising power level shown on galvanometer, log n meters, and decreasing period.

NORMAL AUTOMATIC RESPONSE

Safety rods fall into the reactor when the electrical power fails.
Scram II when control rod A.C. fails.
Scram I when power is 120% of normal.
Scram I when period < 2 sec.
Annunciator sounds.

NORMAL ACTION BY OPERATOR

Silence horn
Inform supervisor

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

No damage

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

The decay of xenon poison introduces reactivity into the reactor at a rate equal to $\sim 6 \times 10^{-5}$ k per second, if the reactor has been previously operating at 700 MW. At such a rate, about one hour would be required before the reactor attained a period of 30 sec. Unfortunately, the burnout of xenon poison, as the neutron flux rises, is autocatalytic. Thus, at 100 MW reactor power the rate of introduction of k by xenon burnout is about the same as that by xenon decay. The precise time schedule of the incident will depend, therefore, on the reactor power level at the time when control rod electrical power is lost.

One can say, however, that if no corrective measures are taken, the fuel will eventually melt down in a time on the order of 15 minutes.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

If the incident noted above occurs, operator should

- 1) Press "Scram" button
- 2) If safeties do not fall in, press "Down" button on Safety Rod Panel
- 3) If safeties do not go in press "Dump" button to drop moderator.

INCIDENT NO. 6 (cont'd)

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EMERGENCY OPERATING PROCEDURES

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INCIDENT NO. 7

During unloading of the reactor, too many control clusters are removed. The reactor goes critical when perhaps 12 control positions are vacant. (Standards call for no more than 3 vacant positions).

SYMPTOMS

Rising power level indicated on count rate meters.
Each control cluster removed will cause the equilibrium flux to increase and then level off, while the reactor is sub-critical.

NORMAL AUTOMATIC RESPONSE

None - All control and safety rods are immobilized.

NORMAL ACTION BY OPERATOR

Inform crane control of rising flux
Inform supervisor

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

Same as for "CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION".

CONSEQUENCES FOR NO AUTOMATIC OR EMERGENCY ACTION

If enough control clusters are removed to take the reactor above criticality, the assembly will rise in power to the limit set by the temperature coefficient. In the extreme cases, the fuel may melt, and the D₂O may boil out of the reactor.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

- 1) Operator in control room observes count rate meter and notifies crane control and supervisor of rising level.
- 2) If power level continues to rise, the operators only course of action is to dump moderator, but only on instructions from the supervisor.

EMERGENCY OPERATING PROCEDURES

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INCIDENT NO. 8

A break in D₂O line - this provides up to 0.4 ft² of leakage area.

SYMPTOMS

Decreasing plenum pressure
Decreasing moderator level
Decreasing flow to fuel
Increasing then decreasing fuel effluent temperatures
Decreasing power

NORMAL AUTOMATIC RESPONSE

Scram I when the D₂O level drops 1 foot.
Annunciator sounds.

NORMAL ACTION BY OPERATOR

Silence horn.
If small leak, take supervised shut down.
If large leak, proceed with sequence of actions as given below.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

D₂O loss. Fuel begins to melt in 12 min. (for a large hole).
D₂O begins to boil, liberating radioactivity to the surroundings.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

Reactor power level drops to the afterheat level as moderator level decreases. D₂O loss from system collects largely in a sump (each with 2000 gpm/pumps to Process Water Storage). Since D₂O cannot be returned to system from the sump, the reactor tank ultimately becomes empty and circulation ends. Fuel melts. Contamination results largely from the more volatile fission products. Fuel and less volatile fission products spread outwardly, at a rate depending upon the heat capacity of the structures encountered, by vaporization and condensation until an equilibrium heat transfer condition is attained.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

Three locations for leakage need to be considered:

- 1) leaks in tank or in the outlet piping to the pump suction valve,
- 2) leaks in the system between the pump suction valve and the discharge valve located downstream of the heat exchangers, and
- 3) leaks in the plenum or piping coming into the plenum.

INCIDENT NO. 8 (cont'd)

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SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL (cont'd)

For small leaks a supervised shutdown can be taken.
For large leaks the reactor should be scrammed.
The leakage rate can be reduced on the high pressure system by cutting the A.C. power to the pumps - as soon as the reactor has been scrammed.

For the first leak location given above, if the reactor tank will become empty before the fuel can be discharged, it is necessary to start flowing emergency H_2O through the fuel before circulation is lost as a result of low level in the reactor. In the meantime, for moderate leakage rates it should be possible to salvage clean D_2O by dropping D_2O to the scram tank and isolating pumps and heat exchangers. The rate at which emergency H_2O can be flowed to the fuel for several possible conditions has been estimated to be as follows:

- a) 75 psig at the [redacted] cooling H_2O headers (i.e., A.C. power on H_2O pumps in [redacted] Bldg.), reactor full, no circulation: 10,000 gpm H_2O to fuel.
- b) Same as (a) except that the reactor is empty: 11,000 gpm H_2O to fuel.
- c) 19 psig at the [redacted] cooling H_2O headers (i.e., gravity head from reservoirs), reactor full, no circulation: approximately 1700 gpm H_2O to fuel.
- d) Same as (c) except that the reactor is empty: 4200 gpm H_2O to fuel.

For the second location, the leaking system can be isolated.

For the third location, not only should the A.C. power to the pumps be cut but also, for large leaks, the D.C. power should be cut. If all pumping power were cut and the reactor power level scrammed, the flywheels would provide flow sufficient to maintain the temperature rise below the initial steady state value for 5 minutes. However, while cooling the fuel on the flywheel energy, D_2O would be leaking from the system and the level in the reactor would be decreasing. Emergency H_2O must be started to the process system before the reactor becomes empty. After 5 minutes on the flywheel energy, the pump speed would be about 100 rpm, the circulation rate would be about 3000 gpm, and the Reynolds number in the fuel annuli would be about 2300. Also, at 5 minutes after scram the relative power is about 3%, or 20 MW. With the tank full of water at 45°C, boiling in the fuel annuli will not occur - i.e., the heat will be transferred by free convection in the annuli. The moderator can be

INCIDENT NO. 8 (cont'd)

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SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL (cont'd)

held at 45°C by starting all pumps on A.C. power and circulating through the upflow system only (ca. 7200 gpm). If the level is down only a few feet the tank can be filled up again with D₂O.

However, as pointed out, the reactor tank might be almost empty in 5 minutes as a result of the leak, even though all pumping power were cut immediately. Consider a hole in the piping at the plenum having an area of 0.4 sq.ft. The leakage rate would be 22,500 gpm at full pressure; the reactor would empty in less than 1 minute. If all pumping power were cut immediately, the tank would still be 80% emptied in 5 minutes. Emergency H₂O flow is then started, not only because of the exhaustion of flywheel energy but also because of the low level. While perhaps 1000 gpm H₂O or more would leak through the rupture, the flow to the fuel would be adequate, as shown above. Allow the H₂O to accumulate in the reactor tank. Cut off the H₂O injection when the tank is again full. Start upflow cooling system.

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INCIDENT NO. 9

Sudden loss of all cooling H_2O to the heat exchangers.

SYMPTOMS

Annunciator warns of decrease in raw H_2O pressure.
Decreasing H_2O flow as shown on instruments on water graphic panel.
Rising D_2O temperatures from Q-foils and reactor.

NORMAL AUTOMATIC RESPONSE

Scram II when the H_2O flow to the heat exchangers is < 0.90 normal.
Scram I when the individual fuel tube coolant temperature rises considerably above normal.
Annunciator sounds.

NORMAL ACTION BY OPERATOR

Silence horn.
Inform supervisor.
Emergency action must be taken.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

In about 18.5 hours the D_2O begins to boil, although the scram has taken place. The fuel temperature increases and some of it may melt. It is possible that radioactivity will be liberated to the surroundings.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION (other than safeties falling)

The temperature of the circulating D_2O increases by $3^\circ C$ in the first 2 to 5 sec. while the power level is in excess of UA t for the heat exchangers ($U = 100$). At 30 sec., however, the average D_2O will be a little below steady state level. D_2O and H_2O temperatures in the heat exchangers will rise with only a few $^\circ C$ difference. The A.C. power should be cut off after a few minutes if D.C. motors are operable because the heat load from the pumps becomes dominant. Boiling of H_2O in the heat exchangers is reached in 1.5 hours with an after heat load of 8.5 MW. In 18.5 hours about 75% of the H_2O is boiled out of the heat exchangers and D_2O begins to boil in the reactor as well. In 40 hours, D_2O is boiled out of reactor and circulation is lost. Fuel melts at 42 hours.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

- 1) Establish gravity flow of H_2O from reservoir; or, obtain H_2O circulation from disassembly basin using two 6000 gpm pumps.

INCIDENT NO. 9 (cont'd)

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SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL (cont'd)

- 2) The A.C. power to the process pumps should be cut off within a few minutes after scram in order to reduce the heat load. As the D₂O temperature comes up to boiling (10-18 hours) the D.C. motors should provide sufficient plenum pressure and flow to avoid vapor binding of the central fuel. The pumps should not cavitate seriously or vapor bind until the D₂O level in the reactor is reduced by about 12 ft. (approximately the scram level).
- 3) If D₂O starts to boil in the reactor (ca. 10 - 18 hours), start adding H₂O to the reactor without attempting to salvage D₂O. Keep all six pumps circulating by D.C. motor. To avoid boiling in the overflow about 270 gpm H₂O is required. To boil off the water about 30 gpm H₂O is required.

EMERGENCY OPERATING PROCEDURES

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1382
1401
1402
1403
1404
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INCIDENT NO. 10

Stoppage of H₂O cooling water to the top, bottom, and side shields.

SYMPTOMS

Annunciator panel shows a decrease in normal flow to the shield heat exchangers and an increase in normal temperature of the water from the thermal shields.

Water graphic panel shows a low deionized water flow.

NORMAL AUTOMATIC RESPONSE

Scram II. Annunciator sounds.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

Reactor shutdown by Scram II.
Shields heating at a rate less than 0.05°C/sec. (poor mixing assumed in the shields).

CONSEQUENCES FOR NO AUTOMATIC OR EMERGENCY ACTION

If the scram does not occur and the H₂O cooling flow stops to the shields, the shields will heat up at a rate less than 0.2°C/sec (poor mixing assumed in the shields). In this case, there is some possibility of distorting the shields and jamming the safeties, controls, etc.

If necessary, raw water should be fed to the shields, in the event of permanent failure of the deionized water system, while the reactor is shut down.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

If the scram does not occur automatically, but the instruments on the water graphic panel nevertheless show a low flow of cooling H₂O, the reactor should be shut down in a matter of minutes.

- 1) Drive in controls.
- 2) If this fails, press "Scram" button.
- 3) If this fails, press "Down" button on safety panel.
- 4) If this fails, press "Dump" button to dump moderator.
- 5) Try to resume flow of H₂O to shields, with raw water if necessary.

INCIDENT NO. 10 (cont'd)

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EMERGENCY OPERATING PROCEDURES

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1315
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1362
1401
1403
1404
1411
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November 27, 1953

INCIDENT NO. 11

While operating steadily at 700 MW, the reactor is found to have a completely failed control system. The safeties stick in the up position, the control rods are immobile, and the instrument power fails.

SYMPTOMS

Erratic behavior or no reading on most instruments.
D₂O and H₂O are seen to be flowing normally.

NORMAL AUTOMATIC RESPONSE

None possible, although scrams are called for.

NORMAL ACTION BY OPERATOR

Emergency action is necessary, but no immediate danger exists.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

Reactor operates at steady power.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

Reactor operates at steady power.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

- 1) Press the "Dump" button to drain moderator.
- 2) If this fails, try to free the safety and control rods on the 66-foot level. Some sort of poison must be gotten into the reactor, and the first choice is the control rods, which are cooled by forced circulation, and are thus less liable to damage from overheating than the safety rods.

EMERGENCY OPERATING PROCEDURES

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1364
1373
1374
1381
1384

November 27, 1953

INCIDENT NO. 12

Complete stoppage of D₂O to one Q-foil.

SYMPTOMS

No flow through Q-tube as indicated on flow monitor panel.
High temperature on temperature recorders.
High temperature indicated on temperature panel (lights).

NORMAL AUTOMATIC RESPONSE

Annunciator
Reverse when effluent temperature increases slightly.
Scram II when flow decreases 20%.
Scram I when effluent temperature increases greatly.

NORMAL ACTION BY OPERATOR

Silence annunciator
Notify supervisor

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

The fuel will begin to melt in 13 min. after complete stoppage of flow. Even a very low flow will prevent melting.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

If for some reason the scrams do not occur, and the power level remains at 700 MW, the fuel will begin to melt in 11 sec. after complete flow stoppage.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

In order to prevent possible melting of fuel in a completely stopped up Q-foil, very swift action is required in unloading the failed Q-foil.

- 1) Push "Scram" button.
- 2) If that fails, push "Dump" button to drain moderator.

As soon as the power level has been reduced to the afterheat (about 0.04 of fuel power - this should take about a minute following a scram) shut off the main motors and all but three of the auxiliary motors. Then throttle the D₂O flow to 5000 gpm and raise the control rod forest to clear the reactor for discharge. Run in the discharge precision machine and discharge the failed Q-foil, and disassemble it as rapidly as possible, in order to cool the slugs.

INCIDENT NO. 12 (cont'd)

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November 27, 1953

EMERGENCY OPERATING PROCEDURES

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1304
1317
1334
1312

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1334
1356
1371

November 27, 1953

INCIDENT NO. 13

The reactor is operating at 700 MW, and one or more channels of a septifoil become plugged.

SYMPTOMS

The pressure at the location of the pressure switch in the septifoil supply line increases and liquid level in forest standpipe decreases. Bulb will light on flow signal panel and annunciator will sound if flow decreases considerably.

NORMAL AUTOMATIC RESPONSE

Sounding of annunciator.

NORMAL ACTION BY OPERATOR

Silence annunciator.
Inform supervisor.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

No damage to reactor.
Possible melting of one cluster of controls.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

About 10-20 seconds after complete pluggage of a channel, steam is likely to form in channel and D_2O to be ejected from top of forest standpipe. Rod may melt or sheath be ruptured in additional 30-60 seconds.

It is recommended that the low flow signal for the septifoil coolant be placed on Scram II and that the present septifoil monitoring system be refined so that pluggage of one or more channels will initiate an automatic Scram II.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

If reactor does not scram automatically when annunciator and flow signal panel indicate low septifoil flow.

- 1) Drive control rods in at maximum speed.
- 2) If control rods do not go in, press "Scram" button.
- 3) If safety rods do not fall, push "Down" button on Safety Rod Panel.
- 4) If safety rods do not go in, press "Dump" button to drain the moderator.

INCIDENT NO. 13 (cont'd)

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EMERGENCY OPERATING PROCEDURES

1363
1380
1416

November 27, 1953

INCIDENT NO. 14

The reactor is operating at 700 MW, and the coolant flow to all septifoils stops.

SYMPTOMS

Pressure in upflow coolant header decreases; height of D₂O in forest standpipes decreases; nameplates light above flow signal panel; red bull's eyes on panel light if helium-bubbling dip tubes are operating.

NORMAL AUTOMATIC RESPONSE

Sounding of annunciator.

NORMAL ACTION BY OPERATOR

Drive in control rods.
Silence annunciator.
Inform supervisor.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

Possible reactor runaway.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

About 10-20 seconds after flow stoppage, steam will be ejected from septifoil annuli and water will shoot out of forest standpipes. Control rods may start melting or sheaths may rupture in additional 30-60 seconds.

Power would rise if rods melt partially and sag in the septifoils.

A nuclear runaway is possible.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

If reactor does not scram automatically,

- 1) Drive control rod in at maximum speed.
- 2) If control rods do not go in, press "Scram" button.
- 3) If safety rods do not fall, push "Down" button on Safety Rod Panel.
- 4) If safety rods do not go in, press "Dump" button to drain the moderator.

EMERGENCY OPERATING PROCEDURES

1363
1380
1416

November 27, 1953

INCIDENT NO. 15

Failure in the blanket gas system.

SYMPTOMS

The following abnormal conditions are indicated by back-lighted name plates on the miscellaneous annunciator panels.

- 1) Failure of blanket gas blower.
- 2) High or low pressure in blanket gas plenum.
- 3) D₂ concentration in gas above 2%.
- 4) Low O₂ concentration.
- 5) Gas pressure relief to stack.
- 6) High or low gas flow.
- 7) Helium purging.
- 8) High temperature of helium from purification.

NORMAL AUTOMATIC RESPONSE

Sounding of annunciator

NORMAL ACTION BY OPERATOR

Drive in control rods.
Silence annunciator.
Inform supervisor.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

No damage to the reactor if it is shut down before D₂ concentration reaches lower explosive limit.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

For most of the abnormal conditions listed under "SYMPTOMS", time will be available to investigate cause of abnormality. However, if helium ceases to flow through gas plenum, the lower explosive limit of D₂ could be obtained in 20 sec., based on a D₂+O₂ gas generation rate of 30 cfm. Therefore, the reactor should be shut down slowly if flow ceases, without first investigating cause.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

If helium circulation stops:

- 1) Shut reactor down slowly by driving in control rods.
- 2) Press "Scram" button if control rods fail to respond.

If D₂ concentration rises to 2% in circulating helium:

- 1) Investigate cause and remove if possible.
- 2) If concentration continues to rise, shut down reactor slowly when the concentration reaches 3%.

INCIDENT NO. 15 (cont'd)

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EMERGENCY OPERATING PROCEDURES

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1349
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November 27, 1953

INCIDENT NO. 16

Ventilating system failure.

SYMPTOMS

Failure of any ventilation equipment, or high activity in the stack gas will light a back-lighted name plate on the miscellaneous annunciator panel.

NORMAL AUTOMATIC RESPONSE

Sounding of annunciator

NORMAL ACTION BY OPERATOR

Silence annunciator and notify supervisor

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

Same as "CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION"

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

If no action is taken and radioactive gases are leaking out of the system, activity in the air would increase and present potential hazard.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

If ventilation fan fails:

- 1) Determine cause and repair.
- 2) If activity in air increases to a dangerous level before repairs can be made, shut down reactor slowly.

EMERGENCY OPERATING PROCEDURES

1345

1369

November 27, 1953

INCIDENT NO. 17

Earthquake.

SYMPTOMS

Oscillations of hanging parts, crane masts, etc.

(Early warning from University of South Carolina Seismological Station)

Seismoscope at - 40-foot level activates annunciator and may call for scram.

NORMAL AUTOMATIC RESPONSE

- 1) Annunciators for No. 2 MM (MM signifies Modified Mercalli earthquake scale)
- 2) Scram I for No. 5 MM

NORMAL ACTION BY OPERATOR

- 1) Silence horn
- 2) Inform supervisor
- 3) Emergency action must be taken.

NORMAL CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

Only such structural damage occurs as is caused by the earthquake; no nuclear damage.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

If safeties do not drop in at No. 5 MM, the plenum and shield may be shifted by the earthquake, making insertion of controls and safeties impossible. If at the same time electrical power were lost, the fuel might melt down, boiling of the moderator would follow, and radioactivity could be liberated to the environment.

SEQUENCE OF ACTIONS AS CORRECTIVE MEASURES FAIL

If reactor does not scram after a violent earthquake:

- 1) Press "Scram" button.
- 2) If the safety rods do not fall in, drive in the control rods.
- 3) If that fails, press "Down" button on Safety Rod Panel.
- 4) If that fails, press "Dump" button to drain the moderator.
- 5) In the event of a very bad accident to the reactor following an earthquake, see "INCIDENT NO. 2".

EMERGENCY OPERATING PROCEDURES

November 27, 1953

INCIDENT NO. 18

During operation at 700 MW, one plug above a quatrefoil blows out of its seat and is held fast by the bottom plate of the forest. D₂O spills over the reactor top.

SYMPTOMS

Falling D₂O level in reactor tank, shown by the gage on the graphic panel.

NORMAL AUTOMATIC RESPONSE

Scram I when the D₂O level falls one foot, i.e., when about 100 to 200 gal. of D₂O is lost.

Scram II from high Q-tube temperature when most of D₂O is lost.

Annunciator sounds.

NORMAL ACTION BY OPERATOR

Immediate action is necessary in order to save D₂O.

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

Loss of 2200 gal/min of D₂O. Cumulative loss depends upon how rapidly the operator responds.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

If the D₂O level gage does not initiate the scram almost immediately, it is doubtful that the flow through the Q-tube will decrease enough to initiate a scram due to high temperature at the bottom of the fuel columns. It is calculated that the Q-tube flow will be 90% of full flow when the plug is blown out as mentioned above.

Nevertheless, the falling level will in itself cause the reactor to shut down slowly. After 2 minutes of leaking at the rate of 2200 gal/min, the power level will have fallen from 700 MW to 450 MW.

If the leak is allowed to persist at that high rate, after 9 min. the D₂O will boil out of some Q-tube annuli, and after 11 min. some of the fuel will begin to melt. Most of the D₂O will be lost, in this case.

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INCIDENT NO. 18 (cont'd)SEQUENCE OF ACTIONS AS CORRECTION MEASURES FAIL

If automatic scram fails to decrease the power, this action must be taken manually, so that the D_2O flow may be decreased as rapidly as possible.

- 1) Press "Scram" button
- 2) If the safety rods do not fall in, press "Down" button on Safety Rod Panel.
- 3) If the safety rods do not fall in, press "Dump" button on water graphic panel to drop moderator level.
- 4) If all these fail, drive in the control rods.
- 5) After power level falls, turn off the main motors and all but three auxiliary motors. Throttle the D_2O flow to 5000 gal/min. This is a minor violation of previous rules.

EMERGENCY OPERATING PROCEDURES

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1356
1371
1378

November 27, 1953

INCIDENT NO. 19

A weld between one quatrefoil and its top fitting breaks.

SYMPTOMS

D₂O flow through the quatrefoil will decrease a maximum of 20% and the effluent temperature will rise a maximum of 11°C. If only part of weld breaks, the changes in flow temperature will be less.

NORMAL AUTOMATIC RESPONSE

Operation of one of the safety circuits (Scram I,II, or Reverse) if change in flow and temperature are sufficient, or nothing if changes are small.

Annunciator sounds.

NORMAL ACTION BY OPERATOR

Silence horn
Inform supervisor

CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

No damage to reactor or components.

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

If the weld breaks completely, the quatrefoil could fall a maximum of 1-1/16 in., at which position the bottom fitting will be resting on the bottom tube sheet. The top of the quatrefoil cannot slip out of the top quatrefoil fitting so that it will remain upright. Flow could decrease a maximum of 20% and maximum outlet temperature could be 101°C. The surface temperature of hottest slug could increase a maximum of 10°C. The velocity of D₂O leaking out between quatrefoil and top fitting will be 60 ft/sec. No short time consequences are foreseen. Over long period, the top of the quatrefoil might be eroded by high velocity water. Thus, no quick emergency action is required, but prolonged operation would be undesirable.

SEQUENCE OF ACTIONS AS CORRECTION MEASURES FAIL

If flow and temperature monitor indicate off-normal condition and none of the scram circuits operate, the control rods should be driven in slowly to shut the pile down and the defective quatrefoil removed. If the control rods are inoperative, the moderator level should be lowered slowly to shut the pile down and the defective quatrefoil removed.

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INCIDENT NO. 19 (cont'd)SEQUENCE OF ACTIONS AS CORRECTION MEASURES FAIL (cont'd)

In the discharge basin, an inspection of the quatrefoil should be performed with a view toward determining the cause of the weld-break.

EMERGENCY OPERATING PROCEDURES

1317
1356
1371

November 27, 1953

INCIDENT NO. 20

The reactor is operating at 700 MW. Suddenly rods start moving out at 7.5 ft/min., introducing 0.04% k/sec.

SYMPTOMS

Level Galvanometer
Differential Galvanometer
Log n Meter
d Log n Meter

Power Meter
Annunciator
Power and Period Recorder

NORMAL AUTOMATIC RESPONSE

Control rod reversal at 105% of power ($t = 4$ sec)
Scram II at 110% of power ($t = 5$ sec)
Scram I at 120% of power ($t = 7$ sec)
Control rod reversal when period ≤ 15 sec ($t = 7$ sec)

NORMAL ACTION BY OPERATOR

Silence horn
Inform supervisor

NORMAL CONSEQUENCES IF NO EMERGENCY ACTION IS TAKEN

No damage

CONSEQUENCES FOR NO AUTOMATIC RESPONSE OR EMERGENCY ACTION

If control rod reversal does not occur at 105% of power; no damage is yet done.

If Scram II does not occur at 110% of power, no damage is yet done.

If control rod reversal does not occur when the period ≤ 15 sec., no damage is yet done.

If Scram I does not occur at 120% of power, the power level will rise sharply to a limit set by the metal temperature coefficient. In about 17 sec. the power reaches 1500 MW, and coolant is ejected, decreasing the reactivity. At this time, it is almost certain that the top shield will blow off the reactor liberating radioactivity. At about $t = 47$ sec the fuel begins to melt.

SEQUENCE OF ACTIONS AS CORRECTION MEASURES FAIL

If rods move out without direction by the operator:

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INCIDENT NO. 20 (cont'd)SEQUENCE OF ACTIONS AS CORRECTION MEASURES FAIL (cont'd)

- 1) Operator attempts to reverse direction of rod movement.
- 2) If there is no response to 1, operator presses "Scram" button.
- 3) If safety rods do not drop in, press "Down" button on safety rod panel.
- 4) If safety rods do not go in, press "Dump" button to drain the moderator.

EMERGENCY OPERATING PROCEDURES

1301
1302
1311
1313
1331
1332
1364
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1384

Incident No.		1	2	3	4	5	6	7
Power Level	MM	700	700	700	700 & Rising	10 ⁻⁴	Startup	Shutdown
Main Motors		Fail	Fail					Shut Off
Auxiliary Motors			Fail					2-6 S.C.'s Operating
Physics								
Safety Rods		Fail	Fail			Fail		
Control Rods		Stick	Stick			Withdrawn at Max. Speed	Jam at** Startup	Misch. One Too Many Reptifolds
D ₂ O Darts - Reactor Inlet								
H ₂ O in Heat Exchangers			Fail					
H ₂ O in Shields			Fail					
Instrument Power - Electrical			Fail	Fail	Fail	Fail*	Fail	Fail
D ₂ O Flow to 4-Foil			Fail					
D ₂ O Flow to 8-Foil			Fail					
Blanket Gas			Fail					
Ventilation								
Earthquake								
D ₂ O Dump Valves			Fail					
q-Tubes								
Time to Start Boiling in Annulus	Sec.	10	10	Never	Never	20	Never	38
Time to Blow Out Annulus Completely	Sec.	12	12	Never	Never	22	Never	385
Maximum Annulus Pressure Increase	Psig.	<35	<35	0	0	250	0	<35
Time to Start Melting - Max. Fuel****	Sec.	160	160	Never	Never	42	Never	Never
Time to Start Melting - Av. Fuel****	Sec.	7	7	Never	Never	7	Never	Never
Pressure in Tank (When Fuel Melts)	Psig.	8	10	--	--	7	--	--
Max. Pressure in Tank Under Shield	Psig.	8	10	0	0	28-41	0	8
Does Top Shield Lift?		No	No	No	No	Yes	No	No
Does Nuclear Runaway Occur?		No	No	No	No	Yes. So Defined	No	No
Temperature Rise in Thermal Shields		No	0.2 °C/s	No	No	No	No	No
Damage or Hazard		Possible Melted Fuel	Fuel Melts, Melting Accident	None	None	Radioactive D ₂ O & U in Surround.	None	Radioactive D ₂ O in Building

* Fails after considerable excess; it has been introduced

** Jam during a normal startup when the rising period

*** The controls will not melt if the No. 2 scram circuit control rod flow measurement.

**** Control rod rather than fuel in Incident No. 14

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30 sec. or more,
it is tied in to the