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A REVIEW OF THE PHILOSOPHY AND FUTURE USE OF THE BALL-3X SYSTEM IN THE IPD REACTORS

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A REVIEW OF THE PHILOSOPHY AND FUTURE
USE OF THE BALL-3X SYSTEM
IN THE IPD REACTORS

INTRODUCTION

Distortion of the graphite stacks of the Hanford IPD reactors due to neutron irradiation effects has grown to where major corrective or compensatory action must be taken to preserve the operability of the safety control systems and life of the reactors. For the past few years, the line has been satisfactorily held by an aggressive maintenance program and short-range solutions. However, longer range, more permanent solutions are needed and high priority is being given to studies toward these ends.

All three reactor control systems are being affected by the graphite distortion. However, the horizontal control rod problems are not directly safety related and are not a subject for this discussion. Important from a safety standpoint is the continual and gradual downgrading of the operability of certain vertical safety rods, particularly those in the fringe areas of the reactors where the effects of the distortion are greatest. However, this problem is not expected to reach the point where reactor safety will be jeopardized for some time, and corrective maintenance together with flexible rods are expected to suffice until longer-range solutions now under study can be put in place. Safety rods are also outside of the scope of this discussion.

Important from a reactor life standpoint (and of more immediate concern and the subject of this discussion) is the jeopardy the reactors face from the use of the Ball-3X system. Permanent loss of balls in cracks in the graphite stacks following a ball drop is a real possibility in most of the reactors today. Recent detailed investigations of the internal stack conditions in the K Reactors have revealed gaps opening into the vertical ball channels which are as wide as three inches. The situation is felt to be considerably worse than that which existed in 1961 when DR Reactor experienced a ball drop due to a circuit malfunction. That ball drop (which was the last total ball drop in any of the reactors) necessitated 295 outage hours to remove balls from the reactor and compensate reactivity losses with enrichment. Enough balls remained in the stack to cause a poisoning effect of nearly two per cent $\Delta k/k$. Had it not been for the availability of enriched fuel and flexible supplemental control systems, DR Reactor might have been severely poisoned indefinitely and would have had to operate at a much reduced power in order to remain critical. The total cost of the DR-Reactor ball drop is estimated at nearly a million dollars. The condition of the graphite stack at certain reactors is now so bad and use of the Ball-3X system could be so harmful to production continuity that the present role of the Ball-3X system as an automatic backup to the safety rods has almost become outdated.

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Any means to measurably reduce the probability of an inadvertent ball drop without compromising reactor safety could be a much cheaper alternative to any presently contemplated solutions which are directed towards physically preventing loss of balls to the graphite stacks. Since the philosophy of the Ball-3X system is central to the problem, it becomes important to carefully review this philosophy and to ask if changes in it (which would offer relief to the present problem) could be made without compromising reactor safety.

It is the purpose of this paper to 1) review the Hanford philosophy of the Ball-3X system from the system's inception to the present use, and 2) pose various questions, the answers to which should hopefully lead to a logical conclusion regarding the future use of the Ball-3X system. The information is presented specifically for the General Electric Technological Hazards Council as background material for full-council review.

SUMMARY

Background information is presented for a forthcoming review of the IPD control philosophy governing the Ball-3X system by the General Electric Technological Council. The original functional criteria of the ball systems are discussed and are used to show the change in philosophy which occurred when the ball systems were first installed in 1951-2 as replacements for the original liquid borax systems. The change was away from "last-ditch" control to one of automatic backup control to the primary safety system. Changes in the systems throughout the intervening years, which have reduced their use in the reactors are also discussed. Differences in system use between the K Reactors and smaller reactors are described.

A series of questions is asked and our philosophy is presented in answering these questions. The pertinent points are summarized as follows:

1. The IPD production reactors need a backup safety control system.
2. The backup system should be separate from the primary safety control system.
3. The backup system should be activated automatically in the event of accidents capable of disabling the safety rod system.
4. System actuation should be direct upon coolant loss and, upon seismic indication, coincident with failure of safety rod system.

Current theoretical studies are being undertaken to evaluate the possibility of reducing the size of the Ball-3X system. Such reduction may significantly reduce the consequences of an inadvertent ball drop.

Council review of the subject is requested, particularly with regard to the following questions:

1. Is the Hanford IPD philosophy regarding the Ball-3X system too conservative?
2. If so, would there be a significant reduction in over-all safety if the Ball-3X system were relegated to a manual tripped system only? If not, should the broader protection of the K-Reactor systems be extended to the smaller reactors?

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BACKGROUND

The first Hanford production reactors were built with a liquid borax third safety system. The liquid was dumped, under pressure, into the vertical safety rod channels. The channels were originally lined with watertight thimbles. This "3X" safety system was tripped only by manual means and in a restricted sense was a last-ditch system.

About 1950, serious deficiencies in the liquid safety system were recognized. The principal of these was the possibility of boiling and expulsion of the poison solution at increased graphite temperatures (resulting from increased reactor power levels). In addition, there were leak possibilities which could inadvertently inject an irretrievable poison into the graphite which would permanently poison the reactor. A replacement system became necessary.

In 1951-52, the Ball-3X concept was developed and installed on the five Hanford reactors in existence at that time. As C Reactor and the two K Reactors were built in succeeding years, Ball-3X systems were made a part of their designs. N Reactor also has a Ball-3X system.

The original functional criteria¹ for the Ball-3X systems are of interest in giving clues on the safety philosophy at that time.

1. The system is to provide adequate control strength to shut down and hold down the reactor under all accident conditions, including vertical rod failure due to graphite distortion, earthquake, or blast damage. The intent that the system is to back up the safety rods if they fail is explicitly stated in this first criterion. This is the first evidence of a transition from the "last ditch" philosophy of the liquid borax system to a backup philosophy. Graphite stack distortion was recognized as being capable of causing safety rod failures and thus rod backup was deemed necessary. No doubt, the choice of a fluid-like material (small ball shot) was governed to a large extent by the need to provide a backup system which had a higher probability of entering a grossly distorted graphite stack than the vertical safety rods.
2. The first balls must reach the bottom of the graphite stack within (X) seconds after the hopper was tripped.
3. The system must be automatically tripped if a low inlet water pressure trip occurred within (X) seconds after a scram. This criterion puts the Ball-3X into the automatic backup category. However, the tripping is direct and presupposes vertical rod failure. This is reasonable since an accident severe enough to cause a low inlet water pressure trip in so short a time means a severe pipe break has occurred; earthquake resistance studies² have shown that the inlet piping is more resistant to failure under severe shock conditions than the vertical safety rod system.

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- 1 Ball Third Safety System for 105-B, D, DR, F and H, HDC-2336, October 1951.
- 2 Holmes and Narver, Inc. Final Report - Earthquake Resistance of the Existing Hanford Production Reactors, HN-146. June, 1960. (CONFIDENTIAL).

4. The failure of vertical safety rods to properly enter the reactor must be detected and automatic ball drop backup provided. Here again, the automatic backup concept is expressed, but the tripping is indirect instead of direct as in Criterion 3. The balls are dropped only if the rods fail. Hence, a sensing device had to be incorporated into the tripping system which was capable of detecting rod failures and causing the appropriate backup action of the ball system. Such devices were included in the C and K designs, and were added to the other reactors.
5. The trip circuit must be designed fail safe, so that a failure of a component would result in a ball hopper trip. There was no expectation at that time of the severe economic penalties now associated with inadvertent ball drops (other than the reactor downtime necessary to remove the balls from the vertical control channels after a drop).

Later, the Ball-3X systems at the three newest reactors (C, KE and KW) were connected directly into the seismoscope safety circuit. The vertical safety rods were already in this circuit. Again, a direct trip was employed, the philosophy being (as on Criterion 3) that the occurrence of a seismoscope trip (at MM-5)³ increases the probability of safety rod failure and ball insertion will probably be required. This trip function was later removed at C Reactor. It has been revised at the K Reactors to provide an indirect backup function which, similarly to the philosophy expressed in Criterion 3, presupposes a failure of the safety rod system but, similarly to the sense-failure-then-trip philosophy expressed in Criterion 4, provides a sensing system to detect rod failures. At present, upon a seismoscope trip at the two K Reactors, a time delay relay is started which, if not cancelled in five seconds by a low-trip signal from the flux monitors (indicating proper safety rod scram action), will cause a drop of part of the Ball-3X system. All but the outer six ball hoppers in each K Reactor are so connected.

There has also been a change in the dependence placed on the Ball-3X system which has acted to broaden the function of the system. The option now exists of depending upon the system in certain long reactor outage situations to supplement already-inserted control and safety rods in providing adequate hold-down control "at the ready" in the event of water loss. There are other means to supplement the inserted control and safety rods, but the use of the Ball-3X system in this capacity has often been the most efficient. However, present fears of inadvertent usage of the system has lessened this practice. The usage just described has not been considered as being detrimental to reactor safety, however. It is merely a case of requiring a broader function for the Ball-3X system and in so doing does not jeopardize any of its backup features.

It is evident that the replacement third-safety systems (Ball-3X) were originally intended to be broader in scope than the liquid borax systems they replaced. A transition was made from a last-ditch concept to a backup concept. A last-ditch system is to be used only if all other available systems completely fail. Under such an assumption, the system is never really expected to be used, and if it is used, the reactor may be rendered useless for future operation. Such a possibility

³ The seismoscope trip setting has been recently reduced to MM-4.

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is reconciled by the fact that an accident requiring last-ditch action is apt to be so severe that the reactor would be put out of commission anyway. The Ball-3X system does preserve some minor last-ditch features, such as the manual trip. However, the system's automatic tripping features take it out of the last-ditch classification. Furthermore, the requirement that the system is never expected to be used has been violated. There have been a number of Ball-3X drops due to circuit and mechanical failures, personnel errors and, in two instances, a slow safety rod⁴. The fail-safe criterion also implies that the system's usage is not consistent with last-ditch philosophy.

What were the reasons for changing from a system which was essentially a last-ditch system (liquid borax) to one which is essentially a backup system (Ball-3X)? In addition to the aforementioned reasons for abandoning the liquid poison system, there are two other important reasons. The first is that safety rod sticking due to graphite distortion was becoming a problem in early fifties and it was felt that automatic safety rod backup was a prudent hedge against such difficulties. (Flexible safety rods were also introduced at that time to overcome rod insertion difficulties.) The second reason was an increased concern about reactor safety. Higher power levels and more severe operation made improved safety an obvious goal.

PRESENT SITUATION

Since their installation, the Ball-3X trip circuits have been modified to correct design deficiencies which became obvious, usually after a system failure resulting in an unnecessary ball drop. One of the first modifications was the elimination of the rod-failure sensing circuits. These circuits were so unreliable in causing unnecessary ball scrams that their continued use became untenable. This may be looked on as the first step in outwardly appearing reduction in the safety status of the usage of the backup safety control system. It was warranted from a reactor efficiency standpoint (a whole week is necessary to remove balls from the smaller reactors after a ball drop). Was it warranted from a safety standpoint? How much safety was sacrificed? Answers to these questions should become obvious in later discussion.

The sole vestige of the sensing-backup function exists in the two K Reactors, namely the seismoscope-flux monitor intertie described earlier.

The potential for permanent loss of balls in cracks in the graphite stacks following a ball drop has also had an effect in downgrading the backup protection of the Ball-3X system. The removal of the direct seismoscope trip in the Ball-3X safety circuit in the C and K Reactors can be partly attributed to this problem and can be considered a second step in the reduction in the backup safety status of the Ball-3X system. The questions asked above also need answering here.

In the interest of production continuity, there is increasing concern over the present graphite stack conditions and what the consequences of a ball drop would be. Further reduction (or even complete elimination) in the number of automatic

⁴ In 1952, one slow rod at a scram in C Reactor caused the corresponding ball hopper to trip. A similar case occurred in KE Reactor in 1955.

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trips in the Ball-3X circuit is being sought in some quarters. Such modifications would become the third step in the continual downgrading of the Ball-3X system.

HANFORD CONTROL PHILOSOPHY

The control philosophy of the Hanford IPD reactors encompasses four separate control systems. The horizontal control rods are used for operational and shutdown reactor control only and are not required or depended upon for any fast-acting emergency control. (Their shadowed strength is counted, however, for hold-down control in the dry reactor if they are already inserted in the reactor at the time of coolant loss.) The primary safety control system is the vertical safety rods. This system provides the primary reliance for fast-acting shutdown control in the event of a power excursion, coolant flow interruption, power loss and earthquake. Under the extreme accident condition of a dry, xenon-free reactor, the combined hold-down margin of the HSR's and VSR's is insufficient (to varying degrees at the various reactors) and supplemental control (chiefly in the form of splines) must be used. Splines are also used to compensate for long term reactivity gains and to supplement the control rods during shutdown for long outages. As has been discussed, the "third safety" or Ball-3X system serves as an automatic backup system to the vertical safety rods. The Ball-3X system is also counted upon to provide the extra hold-down control in the event of coolant loss, although splines have begun to supplant this function.

There is therefore some functional overlap among the various control systems. This can be better seen by referring to the figure in which the overlap among the various control systems is graphically shown. (The suggestion is also made in the figure that the Ball-3X system still has some last-ditch features.) The functional philosophy and overlap of the IPD reactor control systems differs from that of power reactors. This is particularly true with respect to backup and last-ditch control. An important question might be whether the Hanford philosophy is over conservative, and if so, whether modifications can be made in the use of the

FUNCTIONAL DUPLICATION OF REACTOR CONTROL SYSTEMS

<u>System</u>	<u>Operating Control</u>	<u>Hold-Down Control Wet</u>	<u>Hold-Down Control Dry</u>	<u>Primary Safety</u>	<u>Automatic Backup Safety</u>	<u>Last Ditch</u>
HCR						
Suppl.						
VSR						
Ball-3X						

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Ball 3-X system which would considerably reduce the present risk of permanent reactor poisoning after a ball drop without compromising nuclear safety. The remaining discussion is directed towards providing answers to these and other questions.

BASIC QUESTIONS

To best utilize the services of the Council, we are submitting for Council review a series of questions and answers which are intended to define our philosophy of the Ball-3X system.

1. Does a Hanford IPD reactor need a backup safety system?

The key to this question is whether the primary safety control system (vertical safety rods) can "fail on demand" at some point in the reactor life. The answer is that failures have occurred and will continue to occur. These failures have been so far isolated individual rods. Since each safety rod (there are between 29 and 45 in each reactor) acts independently, the VSR's themselves act as the first line of backup defense. For example, there are sufficient safety rods so that a uniform system reduction of up to one-third could be tolerated from a safety standpoint. That is, the remaining rods (if functioning properly) could satisfactorily⁵ shut down the reactor for any accident which is considered credible (and including near-instantaneous coolant loss at equilibrium power). Thus, for isolated individual rod failures, the backup protection is adequately provided by the remaining rods themselves.

Up to now, gross failure of the VSR systems has not been included in the discussion. Such a failure is thought to be conceivable only in conjunction with a severe earthquake ($> \text{MM-7}$) or other severe action (bomb blast, missile, etc.). The primary coolant system piping is resistant to earthquakes of even higher intensity. This is most important since the accident which is most demanding of fast reactor shutdown is the rapid coolant loss accident. Thus, to have an accident situation which would demand the fastest and most reliable scram action, an earthquake of an intensity greater than that considered credible in the Hanford area (or an act of war or sabotage) is required. It has been concluded, therefore, that the probability of a sudden, unexpected, gross failure of the VSR system is vanishingly small. A gradual failure rate due to continued graphite distortion (which could eventually approach total safety rod system disability) is not so improbable, however. But in this latter case, there is no sudden nor unexpected nature to the disability, and periodic monitoring of rod performance⁶ and corrective actions can adequately stave off any unsafe character of such a situation.

Therefore, the fact that rods can fail and are expected to continue to fail warrants some form of backup protection. How extensive the backup protection must be and whether it has to be automatic is discussed in the following questions.

⁵ The use of the word satisfactorily here means "satisfying the requirements of the Speed-of-Control Criterion".

⁶ In effect the safety rods are tested on about a twice-a-month schedule by the fact that they are always inserted in the reactor at each shutdown. Furthermore, measurement of rod drop times is done on a regular period which is short compared to the time for any appreciable change in the graphite.

2. Assuming a backup safety system is necessary, does the system have to be separate from the primary system?

In spite of the low probability of an accident which would cause a sudden disability of most or all of the vertical safety rods, we have judged it prudent to go one step beyond the safety rod backup protection provided by the safety rods themselves. This step is of course the Ball-3X system. The decision for a separate backup system in the Hanford reactors stemmed originally from the uniqueness of the Hanford reactors. In the first place, the Hanford graphite reactors differ from water reactors in that it is necessary (for both operational control and primary safety control) to depend on long, limber control elements moving in fixed holes in a solid stack. The stack is subject to changes - changes which can be sudden (as in the case of a severe earthquake) or which can be gradual (as is the case with graphite distortion). In the second place, the lattices of the IPD reactors are not reactivity fail-safe upon coolant loss, and consequently loss of coolant (which is a shutdown mechanism in itself in many reactors) is a reactivity excursion-initiating event in the IPD reactors. In the third place, the Hanford reactors do not have containment shells and therefore lack an important backup safety feature that power reactors have.

Thus, it has been our opinion that the primary safety systems of the Hanford IPD reactors need a separate backup system.

3. Need the backup protection be automatic or is manual actuation satisfactory?

The answer to this question requires an inquiry into the various accidents which require prompt shutdown of the reactor. Accident analyses⁷ have shown that there are four identifiable accidents which require very prompt backup control protection if the entire primary safety system failed coincidentally with the accident.

- a. Near-instantaneous, total coolant loss during reactor operation.
- b. Primary power failure during reactor operation.
- c. Maximum control rod withdrawal physically possible during reactor operation.
- d. Maximum safety rod withdrawal physically possible during reactor startup.

To require gross failure of the vertical safety rods in coincidence with any of the above accidents requires the occurrence of a very severe external event (such as an earthquake) either as the initiator of the accident (as would be the case in accidents a and b) or in conjunction with the accident (as could only be the case in accidents c and d).

The potential for accidents c and d is soon to be materially reduced by reactor design changes which will physically limit control and safety rod withdrawal rates. These changes will leave the rapid coolant loss accident and power loss accidents as the only ones which can proceed fast enough so that automatic backup control action is required if the safety rods fail.

⁷ Staff Process and Reactor Development. Hazards Summary Reports, Volume I, HW-74094 VOLL and HW-74095 VOLL, 1963. (SECRET).

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Thus, our requirement for automatic backup protection rests on our desire to provide the maximum protection possible with the existing systems under the most severe accident conditions. For example, for the accidents in question to occur from an earthquake, the earthquake would have to be significantly more severe than any earthquake recorded in the vicinity of the Hanford plant during historic time⁸. (Meteor hit, missile or bomb blast are also conceivable events.) Whether to protect against such low-probability events depends to a great extent on how easy and how convenient such protection is to achieve. Up until recently, the automatic backup protection of the Ball-3X has not been considered too high a price to pay for the protection provided; under present circumstances the justification for this protection is being seriously questioned.

If the maximum protection capable is to be provided even under earthquake conditions, then some form of automatic actuation of the backup system is required. Making this judgment, it next becomes important to ask how to provide this protection with the minimum of risk of an inadvertent ball drop and poisoning of the reactor.

On the other hand, it may be judged that our approach is too conservative and that automatic backup protection is not required. An important consideration in making this judgment would certainly be the differences in the consequences of the accident with and without automatic actuation of the Ball-3X system. This subject is touched on in a later question.

4. How should the Ball-3X System be tripped if it is automatic?

In the answer to this question, the wisdom from a nuclear safety point of view of the previously mentioned downgrading of the Ball-3X system is also examined. Originally, each vertical safety rod was automatically backed up by a corresponding Ball-3X channel. This type of automatic backup is representative of the first of three possible choices of providing automatic backup protection.

a. Complete Automatic Backup

Provision of a circuit which detects the failure of each vertical safety rod and trips the corresponding ball channel upon such detection under all failure situations.

This type of backup protection is clearly not necessary when one considers that the safety rods themselves provide a substantial degree of backup. There is no need to drop a channel of balls if an occasional rod fails to enter. Only for a gross failure (greater than a third of the system) is there a possible need to actuate a separate backup system. Thus, the removal of the individual rod failure sensing devices from the Ball-3X safety circuit is not considered compromising of nuclear safety, particularly since other automatic trips in the Ball-3X circuit were retained.

⁸ As far as can be determined, no earthquake shocks have ever caused intensities in the immediate Hanford area greater than MM-3.

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A second choice of automatic backup protection is as follows:

b. Presuppositional Automatic Backup (Direct).

Provision of direct automatic trips to actuate the Ball-3X system upon the detection of any accident which warrants maximizing the probability of achieving adequate nuclear control.

This type of automatic backup protection presupposes that Ball-3X insertion will be required and that delays in sensing rod failures cannot be tolerated. The present inlet coolant pressure trips are in this category. On all eight reactors, a too-rapid decay of inlet coolant pressure (signifying a coolant loss conceivable only from a large pipe break and indicative of severe disturbance such as an earthquake) causes an automatic scram of the Ball-3X system. This is a rapid trip. It is of interest to note that it was a wiring error in this circuit that caused the 1961 ball drop in DR Reactor.

The direct trips in the Ball-3X circuit from the seismoscope which were earlier removed also are in this category. However, the occurrence of a seismoscope trip (at MM4 or greater) would not always be indicative of an accident severe enough to require reactor shutdown, and hence such protection is overly conservative in requiring both safety systems to function. The inlet coolant pressure trip thus better serves the presuppositional backup function.

A third choice of automatic backup protection is as follows:

c. Discriminating Automatic Backup (Indirect).

Provision of a circuit to detect failure of the vertical safety rods in conjunction with only those accidents which could lead to an inoperable safety rod system.

An example of the third type of automatic backup protection is the present seismoscope-flux monitor intertie in the K Reactors which was discussed earlier. In this type of automatic actuation, the performance of the safety rods are audited in those accident situations capable of causing the rods to fail (earthquake), and upon failure detection, the ball system is scrambled. At present the ball backup is on an all-or-none basis (six outer ball channels are excluded). This alternate is the most desirable one from the standpoint of maximizing process continuity since a coincidence is required. However, the discriminatory trip may be employed only when the characteristics of the accident and of the VSR system permit the time delay necessary to sense that the VSR system has failed and determine that backup action is needed. An earthquake shock capable of disabling rods but not interrupting coolant which is followed by a second stronger shock which does rupture coolant piping would be an example of such an accident.

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In our present judgment, complete automatic backup is not warranted. Either the presuppositional or the discriminating type of backup is judged to be satisfactory. Whether the two types are redundant and whether the present systems are sufficient is considered in the next question.

5. Assuming that automatic backup protection is necessary, are the present trips sufficient?

The two trip paths in the present K-Reactor Ball-3X circuit which provide protection for the water loss accident are not the same in timing. There is no delay in the pressure loss circuit other than the time taken for the pressure to drop to lower pressure trip setting. There is a five-second delay in the Ball-3X actuation in the seismoscope-flux monitor intertie - the time taken to determine if the rods have entered.

Since it is likely that rod failure would occur under lower earthquake intensities than coolant piping breakage, the trip of the Ball-3X system provided by the seismoscope action becomes important for those shocks able to stop the rods but not break piping; the chance is higher that the reactor will already be shutdown if heavier shocks follow which could interrupt cooling. If the coolant pressure loss trip is the sole actuating device (as in the smaller reactors), no backup action would be started until after coolant loss had started. Thus, in a conservative sense the seismoscope trip provides some added protection; the two trip signals are not truly redundant and both are required for sufficient protection. One acts as an advance trip - working to have the reactor scrammed as early as possible in the event of a damaging earthquake accident and the other works directly from a signal which indicates promptly that the reactor should be shut down.

The principal reason which has differentiated the K Reactors from the others in this dual protection has been the faster ball-removal ability of the newer reactors.

The trip from the seismoscope-flux monitor intertie in the K Reactors is also sufficient in the power-loss accident if the accident-initiating event is limited to earthquakes. However, in the six smaller reactors, the automatic Ball-3X protection is presently only that derived from the inlet coolant pressure trip. Thus, only in the loss-of-coolant accident would the balls be scrammed - failure of rods coincident with a power-loss accident would not cause any automatic actuation of the Ball-3X system in those reactors. Due to the present unsatisfactory conditions of the graphite in the K Reactors, the situation in all the reactors with respect to ball removal time has probably been equalized. Thus, there is less of an economic reason for the reactors to be different in the Ball-3X protection. To resolve the inconsistency between the reactors, either the smaller reactors should add the seismoscope-connected trip or the K Reactors should remove it. It is our conclusion that both trip circuits are necessary.

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6. If both Ball-3X trip circuits are necessary, how can the consequences of an inadvertent ball drop be decreased?

As has been indicated earlier, there are two conceivable accidents (after the planned reactor modifications) which require prompt reactor shutdown if the safety rods fail in coincidence with the accident. The power-loss accident which necessitates switching the reactor to emergency cooling is the less severe in terms of hazardous outcome. There will not be a reactivity excursion so long as major coolant voiding by boiling is prevented. The primary demand for the prompt shutdown is therefore to maintain the reactor heat generating rate during the shutdown within the coolant capabilities of the emergency systems. Theoretical study is currently in progress on the nature of the shutdown power transient for various modes of reactor shutdown including both automatic and manual Ball-3X scrams. It is felt that the calculations will show that in a power loss accident involving complete safety rod failure, only a part of the Ball-3X system need be set to trip automatically. Hence for the boiling protection in the power-loss accident, a significant reduction in the consequences of an inadvertent ball drop may be made by reducing the number of ball channels which are set to scram automatically. This would be particularly true if those channels which are in the worst condition could be the ones which are deactivated.

The other accident, rapid coolant loss to the entire reactor, is a much more severe accident and the ultimate consequences, if coolant cannot be restored, is a reactor meltdown with a high potential for widespread fission product release. The theoretical Hanford analyses of the loss-of-coolant accident at equilibrium reactor operation have always been of an idealized nature, based on conservative assumptions and calculational techniques. The fastest rate of coolant loss has been somewhat arbitrarily assumed to be that resulting from a decrease in inlet riser pressure to one-half of its initial value in one second⁹. In addition, it is always assumed that the vertical safety rods are the principal external shutdown mechanism and that the rod insertion times are not affected by the accident.

If the reactor were operating within the limits set by the Speed-of-Control criterion, the proper action of the safety rods plus the inherent shutdown effect of the Doppler coefficient would prevent the melting of any uranium during the rapid power excursion resulting from the voiding of the coolant. Therefore, while any steam-water mixture is still present in the reactor and able to transport material from the reactor core, no fission products would be available for ejection. After the reactor is made subcritical, fission product decay would continue to heat the reactor and eventually the uranium melting point would be reached resulting in the release of fission products. However, the melting due to decay heat would not occur for some number of hours after the loss of coolant (depending on the power level at the time of the accident). Thus, the combined shutdown action of the safety rods and Doppler effect materially delay fuel melting and prevent a puff type release of radioactive material. This is the key philosophy of the Hanford Speed-of-Control Criterion. The ultimate outcome of such a "controlled" coolant loss accident occurring during reactor operation would be a full-reactor meltdown.

⁹ Brown, J. H. Review of the Speed-of-Control Criterion, HW-53693, November 22, 1957. (SECRET).

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The meltdown would be in a subcritical reactor, however, and the release of fission products should occur nonviolently.

If the safety rods failed to enter the reactor, the slower Ball-3X system (if set to trip automatically) then becomes the final excursion terminating system. Calculations are now being made to assess the outcome of a coolant-loss accident which is terminated by the Ball-3X system. It is expected (at least in the smaller reactors) that even an automatic Ball-3X trip upon coolant loss (assuming the very rapid one-second pressure decay rate) would not be fast enough to prevent fuel melting during the power excursion induced by the coolant loss. Under such accident conditions, the fuel is expected to melt in a very few seconds. The rapid ejection of a mixture of steam and water from the reactor during the boiling phase of the excursion would undoubtedly carry a substantial load of fission products out of the reactor through the piping break. The release of fission products would not only be earlier (in seconds instead of hours), but would be more violent than in the case when the safety rods terminated the excursion.

Although, the speed of the Ball-3X system is not high enough to meet the requirements of the Speed-of-Control Criterion in the worst coolant-loss accident conceivable, it should be adequate in a coolant-loss accident in which the inlet pressure decayed at a more realistic rate. Assessment of its actual adequacy must await the calculations which are in progress.

As in the case of the power-loss accident, it is believed that certain ball channels could be removed from the automatic trip circuits without significantly reducing the protection afforded by the ball backup function in the event of loss of coolant. Again, this would result in a material reduction in the expected consequences resulting from an inadvertent ball drop.

CONCLUSION

We have tried to show in the previous six questions our philosophy of the Ball-3X system. Our answers lead us to the conclusion that an automatic backup system is required in the Hanford IPD reactors. Also, some reduction in the consequences of an inadvertent ball drop may be permissible by reducing the size of the Ball-3X system.

In the reactors most affected by graphite distortion, eventually even a reduced ball system on automatic trip may pose too great a risk to reactor life. At that time, the system will have to be abandoned as an automatic system and a replacement system installed. Study towards this end is now in progress. The ball system could then be retained as a manually-operated last-ditch system.

The simplest solution to our problem as far as reactor modifications and cost is concerned would be a change in our safety philosophy. Although, the present philosophy is not uniformly agreed upon at Hanford, we believe it represents the majority opinion. Your review of our philosophy may show that it is overconservative; in any event review by an external agency should be beneficial.

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The information presented in this brief report will be supplemented by oral presentations at the December, 1963 Council meeting. The Council is requested to review the following specific questions.

1. Is the Hanford IPD philosophy regarding the Ball-3X system too conservative?
2. If so, would there be a significant reduction in over-all safety if the Ball-3X system were relegated to a manual tripped system only? If not, should the dual protection of the K-Reactor systems be extended to the smaller reactors?

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