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**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

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HW-80676

DATE February 3, 1964

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REPORT OF GETHC MEETING DECEMBER 1963
REVIEW OF IPD BALL-3X SAFETY PHILOSOPHY

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AUTHOR

R. Nilson

and

T. W. Ambrose

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REPORT OF GETHC MEETING DECEMBER 1963
REVIEW OF IPD BALL-3X SAFETY PHILOSOPHY

By

R. Nilson and T. W. Ambrose

Process and Reactor Development
Research and Engineering

February 3, 1964

INTRODUCTION

R. Nilson and T. W. Ambrose reviewed the recent structural observations in the graphite stacks of the K plants and the appropriateness of the Hanford IPD philosophy regarding the Ball-3X system with the Hanford Subcouncil on December 10 and with the Council on December 11, 1963, in San Jose, California. This report will serve to record the presentations made by the authors and the reactions of the Council as formalized in the Subcouncil report and the Council Highlight which are included as appendices.

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SUMMARY

Information resulting from recent graphite investigations in the K Reactors were presented to the Council. Separations as much as three to four inches were reported. Contraction of the graphite within the fueled regions of these reactors is now about one per cent in the direction transverse to the extrusion axis of the graphite and about two per cent in the parallel direction. Saturation is not expected until shrinkage of at least two to three per cent is observed in the transverse direction.

The contraction is resulting in two principal operating problems; control rod entry and loss of 3X balls in the separations following a ball drop. The principal purpose of the review concerned only the ball system and particularly the philosophy governing the system's use.

Following a historical review of the ball system philosophy, our present views were developed by the consideration of six questions and answers. Our points extracted from these questions were 1) the IPD reactors require 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 upon accidents capable of disabling the safety rod system, 4) the system actuation should be direct upon coolant loss, and 5) the system actuations should be upon seismic indication if coincident with safety rod system failure.

Results from recent reactor kinetics studies simulating coolant loss and power loss accidents were presented. The results indicate overprotection in the safety rod system for these accidents, some overprotection in the ball system for the power loss accident, but underprotection in the ball system for the coolant loss accident. Some reduction is warranted in the size of the ball system which need be automatic on power loss.

The Council agreed that 1) our safety philosophy is not unduly conservative, 2) there is no longer justification for a distinction in Ball-3X coverage among the reactors, 3) some improvements in safety without increasing the risk in false Ball-3X drop could be reliably made, 4) the seismic trip level should be set realistically in view of the purpose it is to serve, 5) the reliability and response of the pressure loss trip might be developed to assure better backup protection against a nuclear excursion; and 6) the recovery of the reactor after use of the Ball-3X system may be improved by removing the outer, crack-containing channels from the system without otherwise impairing the essential function of the Ball-3X system. It was recommended that the last item be done.

DISCUSSION

Graphite Stack Observations

During the past six months, an instrument developed for monitoring channels in the graphite stacks has been checked out, and twenty-two vertical safety rod channels in the two K plants have been examined, including photographing and measuring.

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The average exposure of the graphite being examined is in the neighborhood of 4×10^{21} nvt with operating temperatures experienced from 250 C to 700 C which have increased correspondingly to the power ascensions recorded during the lifetime of the K plants. The nature of the graphite stack layup-design is significantly different from that of the earlier constructed Hanford reactors in that the K plants were designed to accommodate graphite expansion. Following K plant construction the graphite contraction phenomenon was discovered, and the stacks were somewhat more vulnerable to stack damage because of design. The problem has been further aggravated by the higher neutron exposures and temperatures which are associated with the K plants. The following discussion is preliminary in nature but represents what is known of the stack conditions to date and some indication of the expected behavior of balls in the event of a Ball-3X drop.

Separations of as much as three to four inches have been observed in certain regions of both K reactor stacks. These separations are the result of high temperature irradiation induced contraction. At the present time the contraction of the graphite blocks within the fuel region of the stack is approximately one per cent in the direction transverse to the graphite block extrusion axis and two per cent in the parallel direction. (Extrapolation of data from high flux test reactors suggests that contraction is not likely to saturate until shrinkage of at least two to three per cent is observed in the transverse direction. No saturation in the parallel direction has been observed.) Because of keying, friction and other mechanisms, the shrinkage of each individual block generally does not merely result in small separations between adjacent blocks, rather, the blocks will tend to slide together so that a single large gap is formed.

Continuous graphite contraction is resulting in two principal operating problems; control rod entry and loss of 3X balls in the separations. The method by which these separations are formed may be visualized by considering the changes which may have occurred in various regions of the stack since startup. The stack may be broken down into three general regions; the moderator, the top reflector, and the side reflector. The stack at the time of layup is shown in the sketch (Figure 1).

FIGURE 1

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The moderator is shrinking in all dimensions. Its top is sagging and its sides are being pulled inward. The top reflector which rests on the moderator is sagging because of the moderator shrinkage, however, the individual blocks within the top reflector do not shrink very much. At the present time the top of the stack has contracted about five inches and is contracting at about 0.8 inch per year. While the top reflector may sag, it does not move inward. The side reflectors exhibit a tendency to slide inward in the top but move outward in the bottom. The behavior of the side reflectors is not yet well understood. The next effect of the movement of these three zones is shown in the diagram (Figure 2) of a cross sectional profile as viewed from the front face. The dashed lines represent layup conditions and the solid lines the present conditions. A cross sectional profile as viewed from the side of the stack would be similar, although not as severely distorted.

FIGURE 2

The separations shown are most pronounced in the lower half of the stack. While separations are observed in the upper regions, they are generally confined to the interface between the top reflector and the moderator and are most pronounced toward the sides of the stack.

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If a VSR channel is located in a zone where separations occur, the blocks around the VSR channel may sufficiently spread apart so that the balls leak out of the channel at the layer in which the spreading occurs. In some channels (particularly the extreme outer side channels), spreading is observed over many layers to that a curtain of balls could be trapped in the graphite.

Two types of separation of the blocks around a VSR channel can occur in both tube and filler layers, namely, front-to-rear separation and side-to-side separation. One type of separation will cause ball leakage out of the channel whereas the other will not. These separations are graphically illustrated in Figures 3A and 3B.

FIGURE 3A

At the sides of the stack, the predominate separations are side-to-side, allowing balls to leak out of the channel and run in the front-to-rear direction. These separations are sufficient in width and length that balls can run into HCR channels

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and/or become lodged in the gaps between the reflector and the moderator (as in Figure 1). Separations are also observed in the center of the stack in the filler layers. These separations are relatively small (1/2" to 1") but may allow some balls to leak out of the channels and run in the side-to-side direction.

FIGURE 3B

Ball-3X Safety Philosophy

Document HW-79542 (13-R-12-26) entitled, "A Review of the Philosophy and Future Use of the Ball-3X System in the IPD Reactors," was reviewed. Results of recent reactor kinetics calculations using the spatially dependent kinetics code CLUMSY were also presented.

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It was first mentioned that although the graphite problem was affecting all three reactor control systems, our requested review was to deal only with the Ball-3X system, particularly the philosophy governing its use. The specific questions we desire to review were:

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 manually tripped system only?
3. If not, should the dual protection of the K-Reactor systems be extended to the smaller reactors?

The background of Hanford reactors with regard to last-ditch and backup control was reviewed. It was pointed out that the installation of the Ball-3X systems in 1951-2, as replacements to the old liquid borax system marked a transition to automatic backup control of the vertical safety rods. The reasons for such a transition were 1) the beginning of safety rod sticking (due to graphite growth) and 2) increased concern about reactor safety as power levels were raised and operation conditions were becoming more severe.

The original functional criteria governing the design of the ball systems were reviewed. In brief, the criteria required that the system be fail-safe, be tripped on water loss, be tripped on vertical rod failure and provide adequate shut-down and hold-down control in the reactor under all accident conditions, without dependence on the vertical rods. It was pointed out that, at the time of installation, there was no great fear from false ball drops - in fact the system as originally instrumented was expected to be used (and it has). The present situation in some of the reactors is that serious reactivity penalties may result (approaching permanent reactor shutdown) from loss of balls in the stack following a ball drop. Thus, there is presently considerable concern over the outcome of a false ball drop.

It was pointed out that the original requirements of the ball system were overly restrictive. Also, the feature providing automatic ball insertion upon the failure of any one rod became so troublesome that it was soon abandoned. The addition of the direct seismic ball trip and its later abandonment were mentioned. The K Reactors still preserve an indirect ball trip on a seismic signal ($\gg$ MM4) if the rods fail to enter in five seconds.

The present situation with respect to the ball system usage was reviewed. At present, the ball system can be manually tripped upon water loss at all eight reactors. The K Reactors differ by having the additional indirect ball trip upon a coincidence of seismic trip and safety rod system failure.

The over-all Hanford control philosophy was also briefly reviewed to show the relationship between the various control systems. It was pointed out that there is some functional duplication among the systems, but that this overlap in no way compromises reactor safety. A diagram of the functional overlap is shown in Figure 4.

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FUNCTIONAL OVERLAP

IPD REACTOR CONTROL

<u>System</u>	<u>Operating Control</u>	<u>Shutdown Control</u>	<u>Primary Safety</u>	<u>Automatic Backup Safety</u>	<u>Last-Ditch</u>
HCR
Splines
VSR
Ball-3X

FIGURE 4

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[REDACTED]

Six basic questions were asked and answered by us. These questions and answers were used to develop the logic behind our present Ball-3X philosophy. The pertinent points developed by the six questions and answers are as follows: (the reader is referred to the reference document for the complete text of the questions and answers).

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.
5. System actuation should be upon seismic indication if coincident with failure of safety rod system.

The accidents which require very prompt backup control protection if the primary safety system fails coincidentally with the accident were elaborated on. They are identified as:

1. Near-instantaneous, total coolant loss during reactor operation.
2. Power failure during reactor operation.
3. Maximum control rod withdrawal physically possible during reactor operation.
4. Maximum safety rod withdrawal physically possible during reactor startup.

It was brought out that the potential for accidents 3 and 4 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 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.

Thus, it was concluded that our requirement for automatic control backup protection rests on our desire to provide the maximum protection possible with the existing systems under the most severe accident conditions. For example, in order that the accidents in question occur from an earthquake, the disturbance would have to be significantly more severe than any earthquake recorded in the vicinity of the Hanford plant during historic time¹. (Meteor hit, missile or bomb blast are also conceivable but rare 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 had not been considered too high a price to pay for the backup protection provided; under

¹ 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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present circumstances the justification for this protection is being seriously questioned.

It was also emphasized that upgrading of the coolant systems, particularly the adding of last-ditch systems, has materially reduced the likelihood of a water loss accident from other than catastrophic causes (earthquakes, for example).

Figure 5 shows power and fuel surface temperature (max) transients calculated to occur during the autocatalytic unflowing accident in the K Reactors during full equilibrium operation (4400 Mw). The cases are for the fastest inlet pressure decay considered credible² ($P \rightarrow P_0/2$ in one second); 18 mk is assumed to be the unflowing coefficient (maximum possible under hot conditions). Transients are shown for a proper scram of the VSR system (30 mk) and for two reduced system scrams (17.5 mk and 23 mk). The reductions in the VSR systems are uniform over the reactor; these curves do not represent cases where adjacent rods failed. The units of the abscissa scales are °C for uranium temperature (T_U) and kw for maximum tube power.

The curves show that in all three cases, the VSR's are prompt enough and strong enough to terminate the excursion (Doppler effect is also acting) before fuel melting. The maximum excursion peaks at about 7000 kw/tube (which is about four times equilibrium tube power). These curves illustrate that the response of the VSR's meets the Speed-of-Control Criterion.

The next figure (6) shows the same accident situation, but in this case the VSR's are assumed inoperative and the excursion must be terminated by the slower acting ball system (plus Doppler). (The units for the abscissa scales are the same as for Figure 5.) It is assumed that the signal to trip the ball comes from the LP and VLP pressure gauges on the inlet risers. A pressure decaying through these two trip points (330 and 190 psi) in less than 3.5 seconds produces a ball trip. The time relationships for a one second pressure decay to $P_0/2$ are illustrated in Figure 7. The TORP (top-of-riser pressure) scale is in psi. The LP and VLP trip points are indicated; the operating top-of-riser pressure is 480 psi.

When the Full Council saw Figure 7, some members expressed doubt that the inlet pressure decay would be so slow as shown if the loss resulted from a complete pipe severance. We stated that no quantitative calculations had been made on how fast

² J. H. Brown in HW-53693, Review of the Speed-of-Control Criterion dated November 22, 1957 concluded that instantaneous loss of water pressure represents a too pessimistic view of possible accidents. Instead he recommended (and the ACRS accepted) that the maximum credible accident be one in which the water flow is reduced to 50% of its equilibrium value in a minimum of one second. This assumes an earthquake of intensity less than that capable of rupturing inlet piping (MMB) occurs. Such an earthquake is assumed to topple vent stacks or high tanks which by falling rupture piping, but not one which would occur so fast that the inlet pressure would drop to half value in less than one second. Earthquake intensities greater than MMB are by this decision ruled not credible.

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Figure 5.

WATER LOSS EXCURSION

Figure 6.

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INLET PRESSURE TRIP

(Ball-3X K Reactors)

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FIGURE 7

the inlet pressure would decay following a rapid and complete severance of pipe; the one-second decay assumption was originally made to represent a not too pessimistic situation and one which considered the fastest rate of pressure loss conceivable from an earthquake of intensity less than that capable of rupturing piping directly (MM8). (See footnote 2.)

Figure 6 clearly shows that the Ball-3X system (as presently tripped on coolant loss) does not act fast enough to terminate the maximum unflooding accident before fuel melting. The curves show that uranium melting occurs about two seconds from the beginning of the pressure decay. The tube power in the maximum tube peaks at almost 140 Mw³.

There is nothing new or surprising about the curves in Figure 6. The Ball-3X system was never designed to meet the Speed-of-Control Criterion and is not expected to. The calculations are new, however. This is the first time quantitative calculations have been made to assess the scram value of the ball system; the calculations were made to assess the effect of reducing the ball system size on the accident outcome. Further calculations are required.

It was concluded that, as presently instrumented, the Ball-3X system is not fast enough to terminate the excursion caused by a rapid coolant loss accident during reactor equilibrium operation. The Subcouncil felt that the excursion caused by coolant loss accident, although of extremely low probability (in view of the improvements made by providing last-ditch coolant systems to the reactors which were not in existence at the time the Ball-3X systems were installed) might be better protected against by developing a more rapid trip of the ball system under such severe accident conditions (see Subcouncil report attached).

The power loss accident (primary and secondary) was also reviewed. Again, results of recent kinetics calculations were presented. The shutdown transients (power and outlet coolant temperature) following loss of both primary and secondary power (requiring switching to last-ditch cooling) are shown in Figure 8 for both a VSR scram and a Ball-3X scram. The units for the abscissa scales are °C for outlet coolant temperature and 1000 Mw for reactor power. These curves are for the K Reactors. Only in the K Reactors, as presently instrumented, would there be an automatic ball trip upon power loss. Surprisingly, in this accident situation (which is of higher probability than coolant loss) the ball system is almost effective as the safety rods in maintaining the outlet coolant temperature below the boiling temperature. The only flow driving force assumed available during the part of the shutdown shown is that provided by the flywheel decay of the primary pumps.

Examination of the scram reactivity transients of the two safety systems provides the answer to the ball system's effectiveness in this accident.

3 Calculations completed since the meeting indicate that an earlier triggered ball trip could terminate the excursion before fuel melting. Some reduction in system size may also be warranted, but this reduction may not be useful in reducing the risk associated with a spurious ball drop.

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Figure 9 shows the transients for the two systems. Whereas, the ball response is slower over-all (requiring about ten seconds to reach full-insertion strength compared to about two seconds for the rods), the initial streaming of balls down the channels provides a "curtain" of reactivity poisoning which is worth nearly as much as the fully-inserted strength of the rods and becomes effective almost as fast. This "curtain" effect has been experimentally verified for the N Reactor ball system⁴.

Figure 10 shows additional power loss transients (K Reactor) for scrams with various reductions in ball system strength. (Scale units are the same as Figure 8.) Both uniform reductions (22 mk and 33 mk compared to full system strength of 44 mk) and nonuniform reductions in ball system strength have been studied. The most interesting curve is the one for the system less the ten hoppers in the next-to-outer rod banks (see Figure 11). Even this system reduction, which could be a very valuable step in reducing the risk in false ball drop, provides a power reduction fast enough to prevent coolant boiling with last-ditch coolant supply.

It was concluded that the ball system can provide sufficient backup to the rods for the power loss accident and that significant reductions could be made in the size of the system hooked into the automatic backup circuit. However, only the K Reactors now have such protection (through the seismic-flux decay coincidence trip).

The Subcouncil recommended uniformity at all eight reactors in whatever backup protection is to be provided by the ball system. The K Reactors no longer possess an advantage over the smaller reactors in ball removal capability following a drop. In fact, they may be at a disadvantage considering the present graphite stack conditions in these larger reactors.

The presentation was concluded by again asking the questions earlier mentioned. Discussion followed. The Subcouncil's conclusions are better stated in their own words and their report is attached. Also, the official highlight of the Council is attached. In summary, the review body agreed that 1) our safety philosophy is not unduly conservative, 2) there is no longer justification for a distinction in Ball-3X philosophy among the reactors, 3) some improvement in safety without increasing the risk in false Ball-3X drop could be reliably made, 4) the seismic trip level should be set realistically in view of the purpose it is to serve, 5) the reliability and response of the pressure loss trip might be developed to assure better backup protection against a nuclear excursion, and 6) the recovery of the reactor after use of the Ball-3X system may be improved by removing the outer, crack-containing channels from the system without otherwise impairing the essential function of the Ball-3X system. The last item was recommended to be done.

⁴ Tiller, R. E., Measurements and Calculations to Determine the Ball-3X Reactivity Transient in N Reactor, HW-76371. January 29, 1963. (Unclassified).

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VSR

Ball 3-X

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FIGURE 9

Figure 10

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BALL-3X LAYOUT

- O Current Hoppers
- Fringe Hoppers
- Out of Service Hoppers
(Proposed)

FIGURE 11

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BALL-3X LAYOUT

- O Current Hoppers
- Fringe Hoppers
- Out of Service Hoppers
(Proposed)

FIGURE 11

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APPENDIX I

TECHNOLOGICAL HAZARDS COUNCIL

Production Reactor Subcouncil Report

December 10, 1963

IPD - Ball-3X PHILOSOPHY (Reference HW-79542)

T. W. Ambrose and R. Nilson discussed the recent structural observations in the graphite stacks of the K plant and reviewed the conclusions of the reference document. The THC is being asked to comment on the appropriateness of the safety philosophy being applied to the Ball-3X system.

Definite ledges in the graphite stack and longer openings between bars have been observed. Dropping of the Ball-3X systems would undoubtedly roll balls into regions from which they could not feasibly be removed. It is apparent that no cure is at hand or will easily be found, short of the expenditure of large amounts of money.

It was the consensus of the Subcouncil that the safety philosophy is not unduly conservative. Since the situation in the older reactors and the K's is not similar, there is no longer justification for a distinction in the safety philosophy.

The key question in the safety sensors and the safety system logic seems to be reliability. It seems possible that, with appropriate consideration for reliability, some improvement in safety could be achieved without increased risk in false Ball-3X drop.

Consideration should be given to alternative roles which the seismic trip may play: 1) It can provide pre-warning, by a sensitive setting, and be used to drop only the VSR's before a significant earth movement occurs, or 2) It can be set at a level to indicate the actual occurrence of an earthquake of near damaging magnitude, in which case the protection provided by the Ball-3X system is appropriately called upon. It is the opinion of the Subcouncil that the Ball-3X system need not be on a sensitive (prewarning) seismic trip. It is understood that if the ball system is used on a seismic trip it is always in coincidence with at least one other trip signal, such as power loss, high flux, or lack of flux decay, which would confirm the condition requiring the Ball-3X drop. In any event, the seismic trip level should be set realistically in view of the purpose it is to serve.

Fast reactivity response is most urgently required to prevent major damage in the case of water loss. The reliability and rapid response of the pressure loss trip might be developed so as to assure the protection against nuclear excursion in this case. It is not apparent that this is presently the case.

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Data were also presented indicating that an adequate safety backup for the power loss accident might be provided by a system having less reactivity control.

This review has again brought attention on the value of the water system reliability improvements that have been made. This reliability must certainly be maintained.

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APPENDIX II

COUNCIL HIGHLIGHT

USE OF BALL-3X SAFETY SYSTEM IN IPD REACTORS

The Council believes that the Ball-3X system should not in principle be restricted to manual scram. It would appear, but should be confirmed on detailed analysis, that real benefit on the water loss accident could be obtained by an automatic pressure loss trip of the Ball-3X. The seismic trip on Ball-3X appears less useful, being more subject to spurious scrams. However, the vertical safety rods should be retained on seismic scrams. In any event, the recovery of the reactor after use of the Ball-3X may be improved removing the outer, crack-containing channels from the system without otherwise impairing the essential function of the Ball-3X system. It is recommended that this be done.

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