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POISON COMPENSATION WITH THE XENON OVERRIDE

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June 12, 1962 *for*POISON COMPENSATION WITH THE XENON OVERRIDEINTRODUCTION

The feasibility of operation with an enriched core to "override" the xenon transient and thus reduce minimum downtime has been reasonably well established. /1,2/

/1/ HW-71809, Production Test IP-467-C, Reducing Minimum Downtime," J.F. Jaklevick, 12-6-61

/2/ HW-73105, "Interim Report - Production Test IP-467-C, Reducing Minimum Downtime," G.F. Owsley, 3-22-62

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The principal economic disadvantage of the present technique is associated with the use of boron splines for compensating the reactivity effect of the core during normal operation. The boron-containing splines parasitically absorb the excess neutrons produced in the core thus wasting these surplus neutrons during the operation when the enriched core is compensated by poison; also, because of the relatively slow removal rate of irradiated splines, a significant portion of the potential downtime reduction is used to remove the splines from the core. The purpose of this report is to point out incentives and alternate methods for improved poison control with the xenon override core and to present current plans for resolving these limitations to the xenon override concept.

SUMMARY AND CONCLUSIONS

With sufficient enrichment to provide full xenon override the net loss in full pile conversion efficiency would be about one per cent in atoms of product per MWD. Of course this loss would not occur if the product of the neutron capture in the compensating target material were of value.

Present spline removal rates are limited mechanically to about 10-15 splines per hour; since up to 40 splines would be in the core for the complete override case at an older reactor, 3-4 hours of spline removal time could be required to attain criticality. Accelerated spline removal should be feasible with fairly minor modifications of the withdrawal equipment. Particularly the very low radiation level of the irradiated splines withdrawn from a shutdown reactor compared to the activity following removal from an operating reactor should aid in speeding up the removal process.

The conversion efficiency loss may be partially recovered by replacing a portion of the compensating splines by lithium-aluminum slugs in tubes equipped with PCCF or OFF equipment thus making tritium with the excess neutrons; nuclear safety requirements resulting from the potential flush discharge of the poison would probably require that a substantial portion of the equilibrium spline inventory be retained, thus restricting the conversion efficiency recovery to something less than the one per cent over-all loss which would occur with boron spline control only. This procedure would require a readjustment of the PCCF placement pattern such that a few of the columns were positioned within the enriched core. Also, all discharge of the poison would have to be performed at low flow by positive displacement with dummy elements. Even with this conservative discharge procedure reactivity gain rates with the PCCF system should be markedly increased over those presently attainable with spline removal only.

A permanent but long range objective would be full reactivity compensation of the core by lithium. This would probably require either flush-proof tube closure mechanisms to prevent absolutely rapid poison discharge or lithium-containing splines in place of the boron-containing splines. To achieve the desired gains the principal action planned is as follows:

1. Perform detailed evaluation of the safety aspects associated with the use of the PCCF (and OFF for the K reactors) in the enriched core, and establish appropriate operating restrictions to assure that safety requirements would be satisfied. Restrictions would probably include column location and loading (reactivity weighting and blackness) as well as charging procedures and equipment.

2. Subsequent to this safety evaluation initiate a production test for using lithium elements in PCCF columns at one of the older reactors, and possibly the OFF facility at one of the K reactors. The purposes of the test would be to confirm operational feasibility and to check the accuracy of the reactivity calculations.
3. Recommend modification of the spline removal equipment and procedures such that the withdrawal can be accelerated.
4. Encourage the development of lithium-containing splines having suitable reactivity and mechanical properties.
5. Recommend investigation of the feasibility of developing flush-proof tube closure devices for charge and discharge of lithium elements during operation and of fabricating lithium splines.

Contingent on the results of these investigations appropriate development action will be recommended. Use of lithium splines would relieve the safety problem; however, fabrication of such splines with sufficient lithium concentration may be infeasible.

DISCUSSION

A. Poison Removal and Insertion Procedure

To clarify the problem a description of the current poison compensation techniques utilizing the core is presented in the following discussion. Poison splines are charged with the initial loading of the enriched core to reduce the local reactivity of the core to that equivalent to natural uranium; this requires about one spline for every two and one-half tubes of E-metal. If full poison columns were utilized about one column of poison would be required for every seven-eight enriched columns.* When the enriched core is to be used to reduce the downtime all the control rods are removed first, then the splines in the core are discharged from one tube at a time until the supercritical condition is attained. Thus the supercriticality status will be reached as soon as sufficient poison is removed. Irradiated splines are removed at a maximum rate of 10-15 splines per hour; since about 40 splines would have to be removed for full override, three to four hours of spline removal would be required. After the startup has been achieved about 3-4 hours are available for inserting the poison, a rate which is relatively easy to maintain with present spline insertion ability. Except for this initial few hours the splines remain in the reactor during all operation.

B. Economic Incentives

Conversion Efficiency

It has been calculated that approximately 100 E-columns (150 columns at a K reactor) would be required to fully override the xenon transient. Since the

*It should be noted that with poison columns extra enrichment would be required to support the negative reactivity effect with the target material discharged from the column. If water remained in the tube, three additional E-columns would be required; with solid aluminum two additional E-columns would be required; and with a minimum reactivity strength dummy, such as bismuth or graphite, slightly more than one enriched column would be required to support the minimum reactivity loss of the dummy column.

compensating poison for this enrichment would be in the reactor for nearly 100 per cent of the operating time, the use of a nonproductive poison represents almost a complete loss of these extra neutrons.

The following calculation illustrates the extent of this loss. About seven per cent of the total heat generation in the reactor would be in the enriched core. The average conversion ratio of natural uranium is about 0.87 grams per MWD, and that of enriched material is about 0.74 grams per MWD. Thus the reduction in conversion efficiency of the reactor would be equal to 0.07 times $0.87 - 0.74 = 0.01$ grams per MWD, corresponding to a conversion ratio decrease in excess of one per cent. About 40 tons of enrichment would be required per reactor year; thus the incremental cost difference between 40 tons of enriched and natural uranium would also be incurred annually. (Of course with a smaller enriched core to provide only partial xenon override the costs would be proportionately lower.) If Li-Al were the target material, the irradiation would be comparable in efficiency to a standard E-N load, since full use of these extra neutrons would be available to make tritium. Thus with lithium in place of the boron reactivity compensation the override concept could be utilized with virtually no net loss in irradiation efficiency.

Poison Removal Rate

The current maximum spline-removal-rate of 10-15 irradiated splines per hour is sufficient for most supplementary poison adjustments; however, a faster rate is required to take full advantage of the xenon override technique since startup will be directly dependent on the time to remove poison from the core. A desirable poison removal rate would be such that all the poison could be removed from the core in about one hour. This would require the removal of a spline about every one and one-half minutes, or the discharge of a column of poison about every five minutes. Since the splines have a relatively low radiation level at the time they are withdrawn (because the reactor would have been down for several hours prior to removal), faster rates of spline removal should be feasible at a relatively low cost.

C. Use of Poison Columns for Core Reactivity Compensation

The irradiation of poison slugs in columns equipped with devices for discharging and charging nonfissionable material during operation is a means for poison compensation with the core which may be feasible under specified conditions. (The principal obstacle to discharging poison columns from the core is the potential for a relatively large reactivity gain resulting from the heightened "worth" of a poison column in a peaked flux distribution, and thus the larger reactivity effect resulting from its inadvertent discharge. This is a problem discussed in Section D.) The currently used Li-6 enriched Li-Al slugs would be acceptable for the poison material. Modification of the PCCF and OFF equipment to perform the necessary charging and discharging during operation would be required. Such a system would work as follows: Out of every 8-10 enrichment columns one poison column equipped with a mechanism for operational discharging and charging of nonfissionable material would be required. The full xenon override core would require about 12-15 such poison columns (about 20 columns at a K reactor). When the core was not being utilized for accelerating a startup the poison columns would be loaded with Li-Al. (A few splines would probably be in the core for fine trimming of the local flux distribution.) When using the core for a startup

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the poison would be discharged one tube at a time and at a relatively slow rate by displacing the poison with dummies. After starting up the poison would be recharged back into the core over the next 2-4 hours. Thus nearly 100 per cent of the operation would be with Li-Al in the poison tubes. The following points should be considered in the use of this technique.

1. Exposure of Li-Al

To efficiently utilize the poison material sufficient residual exposure must be attained by the Li-Al slugs. A cursory analysis indicates that the relatively low radiation level of the Li-Al slugs would permit their recharging until adequate exposures were attained. A measured activity value of 15 mr/hr at two feet was obtained a week after discharge from a Li-Al slug discharged from the H Reactor E-N load, a lower activity level than for the lead cadmium pieces routinely recharged in PCCF columns for supplementary reactivity control. Thus recharging should be relatively easy.

If use of the core were required only once every six weeks an exposure level comparable to that attained with the H Reactor E-N load would be achieved within two cycles only (one recharge). Of course more than one recharge would probably be feasible and even desirable to attain high-exposures. Although frequent usage of the core, and thus more frequent discharges of the poison, could possibly decrease the gain from irradiation of Li-Al, such frequent use of the core should increase the outage time savings such that inefficient use of the lithium would not be significant by comparison.

2. Dummies with Minimum Reactivity Poisoning

Since extra enrichment must be invested to support the minimum strength of the poison columns it is obvious that there would be considerable incentive for a minimum poison strength dummy slug. As stated in an early footnote three enriched columns are required to support a column of water, two enriched slugs to support a column of solid aluminum, and a little greater than one enriched column to support a column of bismuth. It is estimated that a graphite slug (a cylinder of graphite probably canned in aluminum) would require no more than one enrichment column to compensate its poisoning effect. Thus, if 12 poison columns were used, at least 12 additional E-columns would be required over and above that necessary using splines as a poisoning mechanism. However, assuming the value of an E-N type load is equivalent to that of natural uranium, this extra investment in enrichment would not increase the cost significantly.

D. Nuclear Safety

Of principal concern from a nuclear safety standpoint is the reactivity gain which could result from the rapid discharge of a full column of poison from the enriched core fully or partially uncompensated by poison. Such an event could occur from the flush discharge of the poison. The associated reactivity gain would probably exceed five mk (prompt critical is in the range of 6-7 mk); the precise effects in such an event will be evaluated with a computer program currently being developed which will be suitable for this type of calculation. Of course the probability of such an event must be foreseen as virtually impossible if nuclear

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safety requirements are to be satisfied. However, the poison column discharge technique could be utilized even if a rapid flush discharge were possible if the probability of such a discharge were very low and the reactivity gain from a flush would be sufficiently reduced that the reactor would be scrammed automatically before incipient tube boiling. Two techniques are available for reducing the reactivity worth of a poison column in the enriched core. First, less than fully black poison could be used, and second, procedural advantage could be made of the fact that the first poison removed from the core would be no stronger than it would be in a normal reactor. Thus with this latter alternative a portion of the reactivity compensation could be held in poison columns and the remainder in splines. To illustrate this technique Figure 1* shows the relative gain from a poison column flush as a function of the number of poison columns which would have been removed previously from the core. Through the establishment of maximum reactivity surges which would be permitted within the safety criteria, the maximum number of poison columns which could be utilized can be chosen.

E. Short Term Solutions - Partial Lithium Compensation

Although detailed studies remain to be performed it is estimated that with only slight modifications to existing procedures it would be permissible to compensate from one-half to two-thirds of the reactivity in the core with relatively "weak" poison columns equipped with slightly modified PCCF or OFF mechanisms. These studies will be completed and production tests will be prepared which will specify the procedural details necessary to assure proper column loading, restrictions and sequence of poison removal, discharge techniques and safety trip settings. Minor equipment modifications will probably be necessary to attain the necessary level of safety protection. The safety protection would be such that flush discharge of the poison would be extremely unlikely in that it would require the breakdown of rigid and straightforward procedures. A controlled discharge rate would be specified which would be within normal limits for reactivity gain rates. However, in the event of an accidental flush discharge, the power level rise and gain rate would be sufficiently low that the nuclear safety instrumentation would effect a shutdown before tube boiling could occur.

F. Long Term Solutions - Full Lithium Compensation

Full replacement of boron by lithium as the compensating poison could be accomplished either by the development and use of lithium splines or by the development of a means for accomplishing the discharge of poison elements during operation without the accompanying possibility of the rapid reactivity gain associated with a full column flush.

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*Figure one was prepared from calculations for a K pile performed by R. A. Chitwood

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