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TITLE

TECHNOLOGICAL HAZARDS EVALUATION
CORE E-Q LOAD

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TECHNOLOGICAL HAZARDS EVALUATION
CORE E-Q LOAD

October 6, 1964

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

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October 6, 1964

O. C. Schroeder
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TECHNOLOGICAL HAZARDS EVALUATION
CORE E-Q LOAD

The United States Atomic Energy Commission recently authorized the production of 110 kg of U-233 by the irradiation of thorium oxide in the Hanford production reactors. This irradiation will be carried out by replacing the natural uranium fuel in all or a portion of the process tubes in several of the reactors with thorium oxide (thoria) and slightly enriched uranium. This reactor loading is referred to as an "E-Q load." Reactor loadings are separated into two types which can be charged independently of each other: (1) a mixed lattice in the central zone of the reactor in which enriched uranium (0.947 per cent uranium-235) and thoria are loaded in separate process tubes in uniform array with a fuel-to-target ratio of about 5.5-6.0 to 1 (core E-Q load), and (2) a peripheral ring of thoria in the outermost process tubes of the reactor with the reactivity being supplied by enriched uranium (0.947 per cent uranium-235) in the process tubes in the immediately adjacent two lattice units (blanket E-Q load).

This safety analysis is addressed to the core E-Q load; however, the specific fringe loading, with properly matched reactivity, has little effect on the basic physics and hydraulics of the reactor so the evaluation presented here is applicable to a combined blanket and core E-Q load. The evaluation applies to both the K and smaller production reactors. A previous report^[1] presented the hazards evaluation for the blanket E-Q load in the natural uranium reactor.

SUMMARY AND CONCLUSIONS

The core E-Q load in the Hanford production reactors will not result in an over-all nuclear safety status for these reactors which is significantly different from that for the present natural uranium fuel loadings. This conclusion is based on a detailed analysis of the modified reactor loading and operation, safety analyses of accidents which are unique to the new loading, and the fact that new procedural controls and devices will be

[1] HW-84096, "Technological Hazards Evaluation - Blanket E-Q Load,"
O. H. Greager, September 10, 1964. (Secret)

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adopted both to minimize the probability and limit the consequences of accidents. In addition, the E-N loadings at the H Reactor have provided an excellent base of experience for any reactor loadings using enriched fuel. The ability to operate the Hanford reactors with enriched fuel and target loadings has thus been demonstrated.

The Total Control, Speed-of-Control, and Coolant Supply Criteria, which are considered as basic tenets of Hanford reactor safety philosophy, will not be compromised in the E-Q loadings.

DISCUSSION

Description of Modification

The natural uranium fuel in the central core process tubes of a reactor (about 1750 tubes at a K Reactor and about 1000 tubes at a smaller reactor) will be replaced with solid elements of thoria, contained in aluminum cans, and slightly enriched uranium (0.947 per cent uranium-235 fuel elements) in the ratio of about 5.5-6.0 columns of enriched uranium to one column of thoria. This loading differs from the E-N load at H Reactor only in that the thoria has a lower capture cross section for neutrons than lithium, thus less supporting enrichment is required, and in that fuel and thoria will be loaded in separate process tubes. (In the E-N load, the fuel and lithium elements were charged in the same process tubes in a striped array.)

A broad testing program initiated about one year ago has demonstrated the satisfactory performance of the thoria target element and the proposed loading arrangement. The enriched uranium fuel is identical to that used in the H Reactor E-N load and for meeting enrichment requirements in the predominately natural uranium reactors. This loading adjustment, which reduces fuel inventories, will require that the power of the average central zone fuel tube be increased 15-20 per cent to maintain the same reactor power. This increase is within plant capability, since power levels are limited by the bulk coolant temperature rise.

Operating Characteristics

Operation of the reactor will not be changed significantly from that with a natural uranium loading. The positive graphite temperature coefficient of reactivity is expected to be larger in the E-Q reactor. This will reduce the minimum cold-clean-reactivity necessary for efficient operation and will increase the tendency for flux cycling. The graphite coefficient will not be significantly larger, however, than that experienced, for example, in natural uranium loadings at the end of a fuel cycle. A smaller long-term reactivity transient is expected in the E-Q reactor, and this should compensate for any increased oscillation tendency. The xenon and

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samarium contributions will be nearly identical for both loadings. Established fuel temperature, coolant temperature, and heat flux limits will not be exceeded under normal full-power operation with E-Q loadings, although the margin between peak operational conditions and conditions capable of producing nucleate boiling or heat transfer burnout will be reduced somewhat.

Scope of General Electric Company Responsibility

The General Electric Company, as contractor to the AEC for operating the Hanford production reactors, will be responsible for preparing the fuel and target elements, planning and carrying out the loading adjustments, and carrying out the research and development required to assure that product quality and quantity objectives can be met, and that the reactors can continue to be operated safely and efficiently. Further, the Company will be responsible for complying with governmental regulations and directives in regard to the safe operation of the reactors and formalization of safety reviews.

An Analysis of Possible Errors and Failures

Only errors and failures having a direct bearing on the reactivity characteristics of the reactor represent a significant departure from operation with a natural uranium core. Possible errors and failures involving coolant flow and mechanical reliability are not affected by the change from a natural uranium loading.

Two classes of related errors and failures are considered applicable to the safety of the core E-Q load which are not applicable to the full natural uranium load. These are mistakes in determining the physics characteristics of the load, and the inadvertent misplacement, omission, or removal of thoria in the mixed lattice of enriched uranium and thoria.

The physics of enriched loads has been well verified by experience with the E-N load at H Reactor and requires only a minor extension to E-Q loads. The uncertainty of the reactivity of the initial loading is 1.0-2.0 per cent which will require special conservatism during initial operation to assure that safety is maintained and that the reactor is operable. However, with these precautions no increased hazard potential will result from the reactivity uncertainty. The reactivity uncertainty of subsequent loads will be no larger than with current natural uranium loads. Representative samples of fuel and target materials will be routinely tested in the Hanford Test Reactor to assure that reactivity characteristics of the fuel and target elements are maintained within specified tolerance levels.

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The inadvertent misplacement, omission, or removal of thoria can result in significant reactivity increases. Accidents of this type which have been analyzed in detail are (1) a loading error which brings the reactor to a supercritical state with safety rods inserted, (2) a startup error in conjunction with such a loading error, and (3) accidental removal of thoria by water flushing. The number of independent errors or events required for any one of these accidents to result in a hazardous outcome are numerous enough so that none is judged credible.

For example, at least four independent errors or failures are required to result in a hazardous condition as a consequence of achieving supercriticality during reactor loading. These are (1) transfer of fuel instead of thoria from storage to the front work platform, (2) failure of charge crew members on the work platform to recognize that they were loading enriched uranium fuel elements instead of thoria elements, (3) failure of reactor operators to detect a rising subcritical neutron flux level as the incorrect loading progresses (an inadvertent rise in the subcritical flux level would be detected when k_{eff} exceeds about 0.98), and (4) failure of safety rods, which are purposely held in scram position, to terminate a supercritical state if it does occur. (At least 14 thoria tubes in a block would require replacement with enriched fuel to override the inserted VSR system.)

Similarly, the startup accident requires, in addition to the initial sequence of errors leading to a gross loading error, the following errors:

(1) failure of a reactor operator to check and note that inlet tube pressures on thoria tubes are low before startup, (2) failure of reactor personnel to make a fuel and target inventory following loading and resolve and correct discrepancies which could significantly alter the reactivity status of the reactor, (3) erring by the reactor operator in withdrawing two adjacent safety rods, and (4) failure of the operator to stop or reverse the rod withdrawals upon receipt of information from the subcritical flux monitors that the reactor is approaching critical. Withdrawal of a vertical safety rod through the peak of the maximum flux-distortion loading-error case would introduce about ten times the reactivity insertion rate as in the normally loaded reactor.

For the maximum flush of thoria to have a serious outcome, a succession of several unlikely errors or procedural violations is also required. The independent errors required are: (1) uncapping (at one time) the rear ends of three to four times the number of thoria tubes permitted uncapped, (2) failing to mechanically seat the thoria columns before replacing front tube caps, and (3) opening all front crossheader valves previously throttled before it was established that the tubes had been properly capped.

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Probability of an Accident

As discussed, procedures and automatic safety backup systems have been designed such that a minimum of three totally independent and unlikely errors and failures must occur before serious consequences could result from inadvertent reactivity insertion in a manner which is significantly different than with a natural uranium load. Thus, it is concluded that the probability of an accident with fuel melting or fission product release is not significantly different from that with a natural uranium load.

Consequences of Maximum Possible Accident

The maximum possible accident (often referred to as the worst conceivable accident) is the same as with the natural uranium reactor, which is nearly instantaneous loss of reactor coolant during full power operation. Complete melting of fuel would result which would release fission products to the reactor building and eventually to the environs. The inventory of fission products will be nearly the same for both loadings.

The use of a mixed lattice of fuel and thoria introduces the potential for one accident of less but comparable consequences as the maximum possible accident. This is the full thoria flush accident. Calculations indicate that a flush of all the thoria in the core would cause a reactivity increase which would very likely exceed the reactivity strength of the vertical safety rods by a sufficient amount to exceed prompt criticality. Because of the resulting rapid excursion, boiling of coolant and uranium melting would take place nearly simultaneously. Voiding of coolant throughout the reactor would further increase the reactivity by about three per cent. If the melting of the uranium resulted in its flowing into the graphite stack, a large negative reactivity effect estimated to be up to about five per cent would be introduced. With the reactor initially subcritical by 3% $\Delta k/k$, the state of the reactor following uranium melting and dispersion would probably be subcritical.

for Manager, Research and Engineering

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