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DESIGN CONSIDERATIONS REGARDING SLUG RUPTURES IN THE INTERMEDIATE POWER LEVEL REACTOR

AUTHOR

W. L. Pearl and C. A. Pursel

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A. B. Carson,
Reactor Design and Development
762 BLDG., 700 AREA

DESIGN CONSIDERATIONS REGARDING SLUG RUPTURES
IN THE INTERMEDIATE POWER LEVEL REACTOR

INTRODUCTION

The minimum shutdown time, to permit accessibility for the Intermediate Power Reactor is estimated to be 38 hours. In case the reactor were shutdown following each rupture this long shutdown period would have serious disadvantages. The desirability of being able to make firm power commitments (independent of slug ruptures) has led to a study of the possibility of continuous operation following a rupture.

There is evidence to indicate that, at the proposed water temperature, the rate of corrosion of uranium may be so high that at least a major portion of the rupture products may have entered the system before the reactor can be shutdown. A pushout of the affected column would then be a pushout of only those slugs which are still intact and the problem would still remain of removing the rupture products from the system.

PURPOSE

The first portion of this report is concerned with the rate of corrosion of a slug following rupture and the possible limitations to the principle of non-shutdown operation. These limitations include a flow stoppage by the ruptured can, undue increase in gamma activity, increased corrosion by the rupture products, and adherence of rupture products to the piping. The latter portion of the document is concerned with design considerations of the shielding and water plant so as to eliminate or minimize the effects of the introduction of rupture products into the cooling system.

CONCLUSIONS

A. The principle of utilizing the high corrosion rate of uranium (and magnesium) and continuing to operate following a slug rupture without an unscheduled shutdown has not yet been found to be impractical or to have any definite limitations.

1. The corrosion rate of uranium at 550°F may be of the order of 40,000 times as high as that at 100°F.
2. The time required for a ruptured uranium slug to lose its integrity probably lies somewhere between a few minutes and seven hours.
3. The time required for a ruptured magnesium-uranium slug to lose its integrity probably lies between several minutes and 3000 hours.
4. The ruptured cans remaining after a slug rupture will probably not block the flow passages in a manner that will burn out downstream slug jackets or process tubes.

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5. There will be little corrosion of piping by the rupture products.
 6. There will be little increase of radiation in areas that are accessible during operation.
 7. It is not known whether access to work areas (near the front and rear water wall) would be limited by the adherence of fission products to the piping and hardware.
- B. Further studies and experiments are warranted. These are itemized under recommendations and their need is established in the discussion that follows.

RECOMMENDATIONS

- A. The rate of corrosion (dissolution) of a ruptured slug should be established for water at 550°F and at a velocity of 25 ft./sec.
- B. Tests should be conducted to determine the possible effects of longitudinal pressures up to 150 lbs./in² on ruptured zirconium cans.
- C. A study should be made of the rate of corrosion of zircaloy-2 by uranium oxide and fission products in water at 550°F.
- D. A complete evaluation should be made of:
 1. The solubility and particle size of the corrosion products and fission products released into the water system as a result of a slug rupture.
 2. The make-up of products that will tend to deposit out of the flowing water system either by some mechanism of adsorption or low velocity of flow.
- E. An optimum method of deposition prevention and/or clean-up for those products that will deposit and adversely affect accessibility should be developed.
- F. To properly bracket the possible operating conditions resulting from a slug rupture, any interim reactor designs developed prior to obtaining significant test data should include shielding beyond the water walls and some type of system for segregation of reactor coolant flow after detection of a slug rupture.

GENERAL

The effects of a slug rupture in the Intermediate Power Level Reactor will be significantly different from those in the present HAPC reactors. Three reasons for this difference are: (1) the cooling water is recirculated which tends to distribute the rupture products throughout the system, (2) the rate of release of the rupture products to the water from a uranium slug may be higher by a factor of at least ten to forty thousand, and (3) the substitution of a water wall for crossheaders may result in a more uniform mixing of the rupture products with the cooling water.

PART A.Incidence of Slug Ruptures

The rate of slug rupture in the Intermediate Power Level Reactor cannot now be predicted since it will depend upon such factors as the degree of success of the slug development program in producing a rupture free slug, the philosophy of operation, and the desired amount of fuel burn-up. However, the possibility of slug rupture must be considered in any design. Quality control of slug fabrication and metal preparation will not reach perfection. If it can be assumed that a slug is developed that is capable of 3000 MWD/T, for example, there will undoubtedly be a strong economic incentive to expose these slugs up to the border line of their capability.

Corrosion Rate of Uranium

The corrosion rate of uranium in water increases with the temperature of the water. When a rupture occurs the uranium will be exposed to a water temperature of from 425°F to 550°F depending upon its position in the slug column. Particles that are swept downstream will reach the 550°F temperature region.

The corrosion rate of uranium in water is not known for temperatures above 437°F. Corrosion rates are listed and plotted in ANL-4862 (1) (Figure 1). The corrosion is a chemical reaction which results in the formation of oxides which are essentially insoluble. However at least some of the fission products are soluble. A mild extrapolation (on the log-log scale) gives a value of approximately 3,000 mg/cm²-hr at 525°F. The accuracy of such an extrapolation can be questioned since the ratio U₃O₈/UO₂ increases with increasing temperature above 400°F and the effect of such a change on corrosion rate is not known (2). S. Untermyer (3) has observed the reaction of uranium with high pressure boiling water. He describes the reaction as "explosive" but states that the piece of uranium grew in size and that the rate of growth could be followed visually. It is not known whether the material would have been carried away if the water had been under forced circulation. It is therefore possible that the rate of dissolution of the slug may be very high in temperature water at a high velocity.

Corrosion Rate of Magnesium

The corrosion rate of magnesium in water also increases with temperature. The corrosion rate is shown in Figure 2, (7). The rate at or near 500°F is an extreme and probably unreliable extrapolation. The value used in the discussion concerning the uranium-magnesium matrix slug was .01 mg/cm²-hr. at 500°F.

The Reactor Handbook (4) states "...magnesium has not yet been used as a major constructional material or fuel-element clad because of its high corrosion rate...". It also lists the corrosion resistance of magnesium as "doubtful" at 200°F and "poor" from 300°F to 600°F.

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Time Required for Slug Dissolution

The time required to completely corrode a ruptured slug depends on the temperature of the water and the amount of surface exposed. In order to establish an order of magnitude for the time required for complete dissolution of a slug in water at 500°F two cases are considered.

Case I

Uranium slug, 0.9" O.D., 0.5" I.D. bonded jacket, split longitudinally

<u>Corrosion rate (mg/cm²-hr)</u>	<u>Time (hr.)</u>
3,000	6.8 hr.
10,000	2.3 hr.

Case II

Uranium slug, 0.9" O.D. 0.5" I.D. unbonded jacket, split longitudinally

<u>Corrosion rate (mg/cm²-hr)</u>	<u>Time (hr.)</u>
3,000	2.5 hr.
10,000	45 min.

The rate of decomposition of a particle is directly proportional to its diameter. As an example of the time involved two cases are considered.

Uranium sphere, diameter 1 cm.

<u>Corrosion rate</u>	<u>Time</u>
3,000	3 hrs.
10,000	1 hr.

Magnesium sphere, diameter 1 cm.

<u>Corrosion rate</u>	<u>Time</u>
.01 mg/cm ² -hr.	30,000 hrs.

On the assumption that the corrosion rate of uranium is a direct extrapolation of known data and that the material retains its integrity, the time required to completely dissipate a uranium slug of the above type is in the range of from 1 to 7 hours.

However, in case the uranium loses its integrity ("explodes" or grows rapidly) the required time would depend upon the particle size. If growth can be followed visually the time would certainly be of the order of not more than 2 to 3 minutes and if the particles were then finely divided the time required for the slug to become either dissolved or to go into a finely divided suspension might be from 2 to 30 minutes depending on the particle size and type of original failure.

The rate of decomposition of a magnesium-uranium matrix slug is complicated by the difference in corrosion rates of the two metals. There will be an initial rapid rate of corrosion of the exposed uranium. The rate following this initial rate will depend upon the type of matrix and the type of failure. An upper limit to an estimate of the time required for complete dissolution is 3000 hours. However, if the matrix consists of uranium spheres which are in contact with each other, the time required may be near to that for a solid uranium slug.

Effects of a Slug Rupture

A slug rupture will increase the shielding and accessibility problems. It will accelerate corrosion and will require an unscheduled power interruption of 38 hours if a shutdown is required.

The effects of the rupture will depend upon the type of fuel elements, type of failure, the water plant facilities and the operational procedure. Two cases are discussed which are believed to bracket the probable effects of a rupture:

Case I.

Magnesium-Uranium Matrix Fuel Element

The corrosion rate is relatively slow (up to 3000 hours). After 20 minutes the activity from the front water wall will be increased by 4%. Fission products may adhere to the piping and water walls in intolerable amounts. The problems concerning, isolation of the fission products and clean-up are discussed in Part B.

Case II.

Uranium Slug, Unbonded Jacket

The slug may be completely disintegrated and be present in the system in solution or finely divided suspension in from 2 min. to 2.5 hours. The activity of the rear water wall will be increased by a factor of two and that at the front water wall by a factor of three.

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Operation Following a Slug Rupture

It appears possible that the dissolution of a ruptured slug may occur so rapidly and so completely that by the time the reactor can be shutdown a pushout of the tube contents would actually be a pushout of nothing but good slugs. If this is the case there may be nothing to gain by immediately shutting down the reactor following a slug rupture. The problem associated with slug rupture may then be one of removal of the uranium oxide and fission products which are introduced into the cooling system. The obvious method of removing the rupture products is by a bleed-off or disposal system and diluting or flushing the recirculating system. This system and the problems associated with it are discussed in Part B.

The method of insuring continuous operation by taking advantage of the high corrosion rate of uranium may be limited by the following: flow stoppage by the ruptured can; corrosion of piping, process tubes and slug jackets; increased radiation from the piping and water walls; and residual activity from the fission products which adhere to the piping, pumps and water walls. A discussion of each of these limits follows:

Flow Stoppage by Ruptured Cans

The ruptured can will be subjected to a compressive force of from 2.6 to 100 lbs/in² depending upon its location in the slug column. The pressure will be approximately 2.6 lbs/in² times the number of upstream slugs. In case 1/3 or more of the flow area were obstructed by can fragments the flow through the tube would be reduced by more than 10% and the reactor would be scrambled by the flow monitors. On the other hand if the obstruction covered less than 1/3 of the annulus the reactor would not be scrambled and no heat damage would be expected to the slug jackets downstream from the obstruction. Portions of the can wall probably would not lodge in the space between downstream slugs and the process tube since the can wall thickness is 1/10 of the annulus thickness.

Corrosion of Piping and Fuel Element Jackets

There will be little corrosion of piping by the rupture products. A homogeneous reactor has essentially the same fission products but in a much higher concentration. Corrosion is a major problem in the homogeneous reactor. However, in the Hanford designed reactor the rupture products will be diluted by the water of the entire cooling loop and the time involved will be relatively short. There is less assurance concerning the corrosion of zirconium but zirconium is normally considered essentially corrosion resistant.

Radiation Intensity

The radiation intensity from the recirculating fission products would be at most 2 to 3 times the normal operating activity from N¹⁶. This estimate is based on the increase in activity that could be expected in case a single slug were completely corroded away and intimately mixed with the water in the primary loop. It was assumed that the slug had been irradiated to at least 600 MWD/T.

In order to shield against this amount of activity an additional 6 to 9 inches in the structural (shielding) walls would be required.

Residual Activity from a Ruptured Slug

In case the fission products from a ruptured slug were allowed to recirculate some of these fission products might adhere to the piping, pumps, heat exchangers and water walls. The amount, kind and rate of such adherence is not known. Possible methods of preventing, minimizing or removing such adsorption are discussed in Part B. It is estimated that the activity from the front and rear water walls would just exceed tolerable levels (6 mr/hr.) if 0.02% of the total activity of a single slug were evenly distributed over the piping and water walls. The half-life might be as long as 20 days if all of the fission products were involved.

PART B.

The eventual method of maintaining water quality in the primary loop will be dependent on the actual mechanism of the slug rupture. Three possible combinations of conditions will be considered for effects on water system design.

Solubility vs. Insolubility

The above discussion emphasized the high corrosion rate of uranium in water at elevated temperatures. The main corrosion product from the uranium-water reaction will be the insoluble uranium oxide. In addition, all the fission products released from the slug into the water stream will have varying degrees of solubility. The data on the solution of fission products in water from oxide particles are meager, but indicate that most of the fission product activity remains with the oxide (2). Large particles above about 100 microns in size can be strained from the recirculating water before they get a chance to settle throughout the system. A Cuno self-cleaning type of filter would be satisfactory for such an operation. Those particles that are soluble can be removed through the primary loop bleed-off system. The fine particles passing through the strainers will present the greatest difficulty in handling. By increasing the normal rate of clean-up flow most of these fine particles may be removed before they have had a chance to settle out in the lower velocity areas. Some work at ANL (5) indicated uranium oxide particles below 10 microns will travel with the bulk of the water and can be removed in the bleed-off. Some specific points of very low velocity that can be remotely drained should be designed into the primary loop to give the particles a controlled place to collect.

Deposition in System

The discussion above dealt primarily with the ruptured slug corrosion products and fission products introduced into the flowing water stream. As long as the materials can be kept in the stream, the clean-up problem is one of replacement of the contaminated water. Because of the colloidal properties and ionic state of the uranium oxide and fission products present, some of the products can be expected to be adsorbed by the metals making up the primary loop system components or products previously deposited on these metals. For

example, this phenomena might be similar to the present filming of aluminum process tubes where the flowing water negatively charges the tubes. This negative charge attracts the positively charged metal oxides. Some oxides are more strongly attached than others and hence more difficult to remove. The effect of these deposits on the accessibility of the system will depend on the products selectively adsorbed.

Several possible methods of control might be used for such a deposition:

1. Prevent deposition

- a. Addition of a negative sol to neutralize any positively charged rupture products.
- b. Addition of a soluble material to complex the troublesome ion into an undissociated form.
- c. Introduction of a suspended material to the water which would prevent deposition by its abrasive action.

2. Deposition Removal

It is especially necessary to remove those products that will limit accessibility.

- a. Dissolution - Any material deposited on the metallic surfaces might be dissolved under certain conditions (as pH adjustment, etc.).
- b. Abrasion - The addition of an abrasive solid to the water system might remove deposited materials.

3. Mechanics of Procedure

No definite recommendations can be made until the nature of the material deposited is better known. To utilize a method of preventing the deposition would require the continual presence of the preventative material in the recirculating water system which might be less desirable than the deposited material itself. A desirable deposition removal system would be able to operate without shutting down the reactor. This may be difficult to do because of the varying effect such an agent may have on the different components exposed to the overall water system. A very fundamental and thorough research program should be instigated to resolve this potential troublesome slug rupture condition. In general, methods of clean-up recommended for use at other sites have required reactor shutdown (2,6).

For the condition of not being able to feasibly remove deposited activity to allow accessibility within a reasonable time, a special shielding wall of about 6 feet of ordinary concrete in front of the front-face water wall (and behind the rear-face water wall) would be required for reactor operation.

Length of Corrosion Time

The previous discussion emphasized how little is known about the rate of

corrosion of uranium in high temperature water and hence the rate of contamination of the water system with corrosion products and fission products.

If a major portion of the ruptured slug underwent complete reaction (dissolution or oxidation) within a period of about two minutes, the method of handling slug ruptures would be merely the simplest means of cleaning up the overall system under possible conditions as discussed above.

If the fuel and fission products are released from a slug over a long period of time, or if some small detectable release occurs for several minutes before the major portion, the immediate removal of the ruptured slug might make a large contribution to the operation of the overall system. For example, upon detection of a rupture, the reactor would be scrammed and in about two minutes the required reactor cooling water could be supplied from a pumping system capable of handling the shutdown flow. The reactor would be quickly brought down in temperature which would effectively decrease manifold the uranium-water reaction rate. The reactor would be put on a once-through cooling system, the tube containing the ruptured slug would be discharged and recharged and the reactor made ready for return to normal operation. Such a procedure, however, would probably require a full shutdown time of about 38 hours. Such a shutdown loop would include one of the primary heat exchanger systems and the front-face and rear-face water walls. The heat exchanger and front-face water wall would be exposed to the recirculating contamination until the system could be changed to the once-through flow. The rear-face water wall would be exposed continually to the contamination given off by the ruptured slug until it was discharged. Though the contamination of the remainder of the primary loop would remain at a minimum, the water walls might require some treatment as discussed in the above before being accessible.

Although slug rupture detection may be greatly simplified compared to our present system by use of high purity water, unless the residues of previous slug ruptures are adequately removed the background activity may greatly interfere with further slug rupture detection.

Any system of slug rupture removal requires the shutdown of the reactor unless the reactor is designed for discharging while in operation. (The use of shielding beyond the water walls might permit manual charge and discharge without reactor shutdown.) A thorough test program of the above may indicate that the corrosion products and fission products introduced into the water system as the result of a slug rupture will not offer any serious accessibility and/or clean-up problems. Therefore, even though the time were available to remove most of the ruptured slug, it may be considered unnecessary to minimize the amount of the material from ruptured slug introduced into the water stream with a concurrent reactor shutdown.

H. L. Pearl

C. A. Pursel

Reactor Design and Development
Design Section
ENGINEERING DEPARTMENT

WL Pearl:CA Pursel:khs

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FIG. 1

Corrosion Rate of Uranium as a
Function of Temperature (1)

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NO. 340R EUGENE DIETZEN CO. PAPER
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FIG. 2

Corrosion Rate of Magnesium as a
Function of Temperature (7)

Corrosion Rate - $\text{Mg}/\text{cm}^2\text{-hr}$

EUDENE DIETZGEN CO.

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Refer to HW-22365

Each line represents an independent set of data
for corrosion rate of Magnesium vs temperature.

1.8 2.1 2.4 2.7 3.0 3.3 3.6
 $1000/T$ (T in $^{\circ}\text{K}$)

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