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IRRADIATION PROCESSING DEPARTMENT

October 14, 1960

REVIEW OF HANFORD PRODUCTION REACTOR CONFINEMENT
(Project CGI-791)

by

R. E. Trumble

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1. INTRODUCTION

The Project CGI-791, Reactor Confinement for Hanford production reactors, was conceived as a result of deliberations concerning the release of the Wahuake Slope secondary exclusion zone for private use, and initiated by an authorization and directive from the Atomic Energy Commission to proceed with such a project on a high priority basis.^(1,2) This authorization was coupled with the establishment of limits on reactor heat-generation rates and fission product inventories. These limits were to be re-evaluated after significant progress had been made toward providing some undefined degree of control of the ultimate release to the environs of any air-borne radioactive fission products which might be released into the building housing any Hanford production reactor.

As a result of this situation, scoping, design, procurement and construction has proceeded in a compressed, overlapping and rather effective fashion. However, the technical information developed for this project is scattered in many documents. And not all of the technical and philosophical bases for the decisions which determined the final scope of the project have previously been documented.

It is the purpose of this report to summarize the philosophical and technical bases for the nature and degree of confinement provided under project CGI-791, to describe the project, and, further, to indicate the expected effectiveness of this confinement system. In discussing the expected effectiveness of the project this report is responsive to a request from the AEC-HOO.⁽³⁾

2. SUMMARY AND CONCLUSIONS

The "Reactor Confinement" project (CGI-791) at Hanford was initiated to provide an originally unspecified reduction in the quantity of fission products which would be released to the environs in the event of release of fission products from irradiated fuel in the Hanford production reactors. The range of incidents to be considered was unspecified. Design and construction proceeded on a high priority basis at the request of the AEC.

The project was divided into phases in order that detailed design and construction could be initiated on parts of the project while necessary development and testing was being done for other phases of the project. These phases were:

- Phase I - Provide fog spray in discharge area
- Phase II-A - Site preparation including excavation
- Phase II-B - Filter building and duct work
- Phase III - Reactor building ventilation modifications and tie-ins

The goal of the project was to provide the maximum feasible reduction in potential fission product release to the environs at an acceptable cost, and with primary emphasis on the release incidents of higher probability (single

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fuel element to one or a few process tubes). The system evolved is designed to:

- 1) Assure passage of air-borne fission products from the vicinity of the reactor through the exhaust filter system.
- 2) Remove at least 99.9% of the particulate matter reaching the filters from the exhaust stream.
- 3) Remove approximately 95% of the halogens reaching the filters from the exhaust stream.
- 4) Provide no reduction in noble gas content of the air stream.
- 5) Have a high probability of functioning as designed as long as the 105 building walls remain intact.

The over-all project was approximately 60% completed on September 30. The fog spray systems are manually operable in all areas. Beneficial use of Phase III is targeted for January, 1961.

Upon completion of this project the already low probability of significant contamination of the Wahluke Slope as a result of production reactor operation will be greatly reduced. However, effective confinement in the event of a full reactor meltdown cannot be assured.

3. ORIGIN OF PROJECT

Although the desirability of providing facilities for reducing the escape of radioactive fission products to the environs in the event of release of fission products from irradiated uranium fuel in the Hanford production reactors has been under consideration for a number of years, incentives could not be clearly developed. The subject was discussed periodically with the AEC and the ACRS. These discussions initiated studies of the effects of potential releases of fission products to the environs, and some consideration of potential confinement methods. In January of 1958, pursuant to discussions with the ACRS on December 20, 1957, the Manager of the Hanford Operations Office, AEC, requested that studies of possible means of containing the Hanford reactors be made on a priority basis. (2) Simultaneously, the power level increases of 20 to 33 percent at the Hanford production reactors which had been proposed to the ACRS at the December, 1957, meeting were denied. Administrative power level limits were established with relief being contingent upon achievements directed towards provision of suitable confinement for the Hanford production reactors.

4. CONFINEMENT CONCEPTS STUDIED

Four preliminary confinement concepts were defined and evaluated. (7,8,9)
These were characterized by:

- 1) Steel dome with fog spray, filtration and iodine removal.
- 2) Building sealing with fog spray, filtration and iodine removal.
- 3) Building sealing with fog spray and filtration.
- 4) Minimum building sealing with fog spray and filtration.

These were ultimately discarded in favor of a fifth concept characterized by positive control of air flow from the vicinity of the reactor through the particulate filters and halogen removers with fog spray provided at the discharge face of the reactor. These concepts are evaluated and compared in the following paragraphs.

4.1 Steel Dome Concept

It would not be feasible to provide a continuous pressure shell around the existing reactor (105) building structure. The nearest approach deemed feasible would provide a steel dome in the form of a flattened "hemisphere" to cover the reactor building. Such a dome, anchored to a massive concrete ring and equipped with air locks could be built to withstand an internal pressure of 2 psi. It was estimated that it would cost forty million dollars to provide steel domes for the eight production reactors. Since the potential overpressure could exceed 2 psi⁽⁷⁾ the dome could not be permanently sealed. If pressure relief, through filters, must be provided, the steel dome acts only as a backup for the 105 building structure. The same degree of confinement could be provided by sealing the building since the building is capable of withstanding such internal pressures as might be developed with a fog spray and a filtered exhaust.

4.2 Sealed Building Concept

Since it appeared that sealing the building could provide essentially the same confinement as a steel dome this concept was examined more closely. Engineering studies (11,12,13,14) established potential internal pressures and indicated the feasibility of reinforcing the reactor buildings to withstand an internal pressure up to 0.3 psig. Materials are available which are capable of sealing porous walls and small cracks and penetrations under test conditions.⁽¹²⁾ However, it does not appear feasible to reduce the leakage rate of the reactor building much below about 5000 cubic feet per minute for a differential pressure of 0.3 psi. This is due to the size and architectural complexity of the buildings.⁽¹³⁾

To provide reinforcement for 0.3 psi differential pressure, and sealing, is estimated to cost \$4,900,000 for all reactor areas. Reinforcement and sealing for 0.1 psi is estimated to cost about \$3,000,000 for all reactor areas.⁽¹³⁾

4.3 Sealed Building Without Iodine Removal Equipment

Both of the above concepts (4.1 and 4.2) included fog sprays at the rear face, filtration for radioactive particulate matter, and provision for iodine removal. At the time of these studies, the method of iodine removal was uncertain, but "caustic scrubbers" were used for estimating purposes. Since iodine removal equipment could be added later, a third

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study case - without this equipment - was considered in the interest of speed. The building sealing costs and feasibility are the same as in Case 4.2.

4.4 Minimum Building Sealing

This was the minimum case studied. It was proposed to seal the building structure only to such an extent that in event of exhaust fan failure the resistance to air flow through the building structure would be large compared to the resistance offered by the exhaust filters. The concept included fog spray and particulate filters.

Funds were provided to proceed with project scope and detailed design based upon this concept.⁽¹⁵⁾

4.5 Controlled Air Flow

As scoping and design studies proceeded it became apparent that while only limited passive confinement could be provided by building sealing, effective direction of air-borne effluent from the vicinity of the reactor through the filters could be achieved by building modifications to permit the air pressure in the vicinity of the reactor to be maintained slightly below atmospheric. This concept requires extremely reliable exhaust fans. The design and construction of such an exhaust fan system has been emphasized.

4.6 Summary of Concepts and Relative Costs

The relative costs of the various concepts are summarized in Table 4-1. It is noted that estimated structural containment costs (for steel domes, or building modifications) range over two orders of magnitude, from \$40,000,000 to less than \$400,000, without marked change in effectiveness.

5. SCOPE OF THE PROJECT

5.1 Description

The confinement systems vary in detail from reactor to reactor. However, in principle and function they are, with few exceptions, equivalent. A typical system will be described, with mention of significant variations where appropriate. The project includes fog spray, filter building and associated duct work, a sample building and associated instrumentation, and in the reactor building proper, modifications designed to provide better ventilation control. These facilities are described below and in Figures I through VI.

5.1.1 Fog Spray

A dense, finely atomized water spray is provided within the discharge area of each reactor. This spray will remove some fraction of any

TABLE 4-1
SUMMARY OF CONCEPTS AND RELATIVE COSTS (For Eight Reactors)

<u>Concept</u>	<u>Dome, or Building Modification</u>	<u>Fog Spray & Filters</u>
4.1 - Steel Dome	\$40,000,000	\$4,000,000
4.2 - Sealed Building	\$3,000,000 to \$6,000,000	\$4,000,000
4.3 - Sealed Building	\$3,000,000 to \$6,000,000	\$4,000,000
4.4 - Minimum Sealing	--	\$4,000,000
4.5 - Controlled Flow	\$350,000	\$4,000,000

*Halogen Removal is not included.

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halogen vapors or particulates that may be present in the exhaust air stream, and will provide some degree of thermal cooling and pressure control. In addition the spray will cover surfaces with a protective film of running water.

Filtered water is provided for the fog spray. The water is pressurized by electric pumps which are backed up by independent steam pumps, corresponding to the primary and secondary process coolant water supply systems.

The fog spray may be actuated manually from the control room, or automatically by means of scintillation crystals monitoring radio-iodine gamma emissions in the exhaust air stream. Automatic actuation of the fog spray is not possible when the access doors to the discharge area are open to permit personnel to be working in this area, although it can be actuated manually.

5.1.2 Filter Building

The filter building is of reinforced concrete lying almost entirely below grade. Exhaust air leaving the reactor building passes through concrete ducts to the building and from the filter building to the existing chimney stack.

The building consists of two identical filter cells with common inlet and common exhaust plenums. Each cell has positions for three banks of filters, which are sealed in place. Each cell has the capacity to filter approximately 3/4 the normal flow. Either cell may be isolated by water-seal pits for removal of contaminated filters without loss of the confinement function.

Initial operation is planned with one bank of absolute filters followed by one bank of activated charcoal halogen absorbers. One bank will initially be unused.

5.1.3 Instrumentation

Direct reading, remote reading (in the reactor control room), and recording instruments will be provided to monitor

- 1) Radiation level in filter cells.
- 2) Pressure differential across filter banks.
- 3) Pressure differential across filter building and ducts.
- 4) Radio-iodine (I^{131}) content in the reactor building exhaust air. (This monitor automatically actuates the fog spray system.)
- 5) Radio-iodine in the filter building exhaust.
- 6) Radiation level of air-borne particulate matter entering and leaving the filter building.

5.1.4 Sample Building

A sample building has been provided for housing detection and sampling instrumentation required for the project. This building is so located that it can monitor the air entering and the air leaving the filter building.

5.1.5 Ventilation Modifications

Modifications to the reactor building ventilation system are required to assure maintenance of less than atmospheric air pressure in the confinement zone upon loss of normal electric power. This will be accomplished by

- 1) Providing automatic transfer from the two electrically driven exhaust fans to the two steam turbine driven emergency exhaust fans in the event of electrical failure. (At each K-Reactor two diesel driven emergency fans will be provided instead of steam driven.)
- 2) The reactor building supply fans (both steam and electric) will be automatically tripped off and the building inlet modulated (with a gravity operated relief valve to protect against excessively low pressures within the building).
- 3) Additional doors and other modifications will be provided in order to direct the air flow from the vicinity of the reactor through the filter building in a more positive fashion.

5.2 Philosophy

The ventilation system is designed to provide positive direction of air-borne effluent from the reactor through the filter building before release to the environs, for all credible operating accidents in which the reactor building walls remain essentially intact.

Loss of both electric and steam power to the reactor building exhaust fans, combined with a simultaneous fission product release incident is not a credible accident unless initiated by an event which is in itself catastrophic, such as an act of war or severe earthquake.

In the old reactors (B,C,D,DR,F and H) earthquake or blast would probably destroy the building walls at, or prior to, the destruction of both steam and electric power supplies. Thus no additional power is supplied to the fans. Sections of the K-Reactor buildings were designed to be blast resistant and therefore might survive an earthquake. These reactors were therefore supplied with a diesel powered emergency fan system to back up the electrical system previously installed. Diesel power was evaluated as being more reliable than steam power under conditions of violence.

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For fission product release incidents, where the building and power supplies remain intact, the controlled-flow, filtered-exhaust confinement concept is expected to provide essentially the same protection as the low-pressure dome with filtered exhaust. For conditions of physical violence which could cause fission product release, the maximum feasible confinement dome would probably be about as subject to damage as the power supplies and the reactor buildings.

For these reasons, and because of the marked reduction in capital cost the controlled-flow concept was chosen.

No building sealing is deemed necessary and none is presently included in the project. Building sealing could be provided in the future if this becomes desirable.

6. PROPOSED METHOD OF OPERATION

The operation of the confinement facilities will be controlled by mandatory standards issued by the Research and Engineering Section of the Irradiation Processing Department and accepted by the Manufacturing Section. Compliance with the standards will be monitored by components within Research and Engineering. This procedure is normal for all process standards which establish process limits based upon preserving nuclear safety, reactor life or, in some instances, operating continuity.

Exceptions to process standards - limited in both scope and time - may be authorized by the manager of Process Technology (Research and Engineering) where special conditions warrant and safe operation is not compromised. Such exceptions are submitted immediately for authoritative technical and managerial review.

The process standards controlling the operation of the confinement facilities will be designed to minimize the release of radioactive materials to the environs in the event of a release of fission products from fuel elements within the reactor (105) buildings.

Although the detailed standards and procedures have not been issued, it is anticipated that operation will be guided by the following rules.

1. During all normal conditions of operation and shutdown the entire gaseous effluent from the reactor building will be directed through the particulate filters and halogen absorbers.
2. During periods of unusual risk of fission product release in the discharge area such as discharge of a ruptured fuel element, the fog spray will normally be kept operating during the period of high risk.

3. Periodic tests will be required to assure that the components of the confinement systems are operative.
4. Reactor operation will be suitably limited during periods when the confinement system is inoperative. For example, discharge operations carrying a relatively high probability of fission product release would be delayed until the confinement system was made functional.
5. The air flow through the reactor building may be reduced in order to increase the fallout of fission products within the reactor building in the event of a major fission product release incident. Positive control of air flow through the filter building would be maintained as long as the monitored effluent from the filter building indicates that the filters are functional. Should the filters become ruptured, due, for example, to excessive plugging, it might be advantageous to stop the fans and maximize the ground-level seepage from the reactor building if the building is intact. The events which could cause such an improbable occurrence as major rupture of the particulate filters in a well maintained system appear to border on the incredible unless associated with another event such as severe earthquake or bomb blast which in itself is catastrophic. In such an event the 105 building walls would probably be shattered and the condition of the blowers and filters of little consequence.

7. STATUS OF THE PROJECT (On September 30, 1960)

On September 30, 1960, the construction status was as follows:

		<u>Percent Completion</u>	
		<u>Actual</u>	<u>Scheduled</u>
Phase I	- Fog Spray	98	98
Phase II-A	- Site Preparation	100	100
Phase II-B	- Filter Buildings	78	80
Phase III	- Ventilation Modification	<u>25</u>	<u>25</u>
		58	59

Phase I: The fog spray systems were manually operable at all areas. All acceptance tests were completed. Purchase orders were placed for essential instrumentation for automatic actuation.

Phase II-A: This phase of the work, as originally defined, was completed in February, 1960.

Phase II-B: The original contract for construction of the filter buildings, sample buildings and associated ducts, piping and wiring was terminated in

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August, 1960. The contract has been assigned to a contractor on a cost plus fixed fee basis. The completion of Phase II-B is now behind schedule, but is proceeding on a high priority basis. The first area (100-F) is undergoing acceptance tests.

Phase III: Substantial progress has been made in design and construction of building modifications and tie-ins. The design is complete, and the construction 25% complete.

The target date for beneficial use of the project in all areas is January, 1961.

8. ESTIMATED EFFECTIVENESS OF THE CONFINEMENT PROJECT

The consequences of a fission product release incident are dependent upon the quantity and nature of the fission products released to the environs, the duration of the release and the meteorological conditions existing during the release incident.

The quantity, nature and rate of release of fission products to the environs depends upon the quantity of uranium fuel involved, the specific heat generation rate (power/unit mass) prior to the incident, the integrated exposure, the interval between cessation of power generation and release, the mechanism of release from the fuel and such devices as may exist which would retain fission products during the migration from the point of release from the fuel to the point of release to the environs.

The cumulative effects of these many variables are very sensitive to factors which have not yet been accurately defined. Pessimistic assumptions have generally been used in generating models. Consequently, it is probable that the potential fission product release from specific incidents considered are significantly overestimated.

The consequences of a given release of fission products to the environs measured in terms of distance and areas affected and in damage to individuals, is strongly dependent upon rate of release, the dilution and deposition downwind, the specific meteorological conditions and the limits at which damage is assumed to occur. These factors are considered in more detail in the following sections.

8.1 Fission Product Release From Irradiated Uranium Fuel Elements

Fission product release studies have been performed at Hanford and at the Oak Ridge National Laboratory. Although these studies are not yet definitive, certain conclusions can be reached.

8.1.1 Melting of Uranium

Evaluation of the results of release of fission products from irradiated heated (molten) uranium shows that general agreement has been reached by various experimenters as to the principal fission products released and the approximate percentages.

Estimates of the maximum release from molten uranium under credible accident conditions are shown in Table 8-1.

TABLE 8-1
MAXIMUM CREDIBLE RELEASE OF FISSION PRODUCTS FROM
MOLTEN IRRADIATED URANIUM

<u>Gas</u>	<u>Maximum Release</u>
Rare gases (Kr, Argon)	100%
Iodine and Tellurium	100%
Cesium	30%
Rubidium	5%
Strontium	1%
Non volatile F.P.'s	1%

The release of fission products is approximately the same in air, CO₂ or helium atmospheres.

In general, the release of fission products is significantly inhibited by the presence of steam; in particular, essentially no Sr90 is released from irradiated uranium melted in an atmosphere in which some steam is present. The inhibiting effect of steam may be due - at least in part - to the protective layer of the oxide formed by the uranium-steam reaction. Significantly more tellurium is released in an oxidizing atmosphere than in an inert atmosphere.

8.1.2 Oxidation of Uranium

Uranium oxide formed in dry air usually appears as a loose powder. The percentage release of the rare gases, iodine and tellurium appears to be roughly proportional to the amount of solid uranium oxidized.

8.1.3 Effect of Concentration

The fraction of a given species of fission product released from molten uranium does not appear to be strongly dependent upon concentration of the species in the sample. The percentage release data obtained for low exposure uranium were consistent with the release data obtained at higher integrated neutron fluxes.

8.1.4 Effect of Aluminum Fuel Cladding

The aluminum cladding combines readily with uranium to form an intermetallic compound at or below the melting point of aluminum. The formation of these intermetallic alloys can retard and inhibit the release of fission products by either melting or oxidation of uranium fuel elements.

8.2 Potential Reactor Incidents

Potential reactor incidents which would lead to air-borne fission product release are associated in every case with inadequate cooling of the fuel element. Inadequate cooling can occur during discharge operations,

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or result from either flow reductions, or power level increases within the reactor.

8.2.1 Inadequately Cooled Fuel

The highest probability for fission product release incidents occurs during the discharge of ruptured fuel elements, when a small fraction of a fuel element may be oxidized after the fuel is exposed to air but before it falls into the water filled discharge chute.

On rare occasions, one or more undamaged fuel elements have hung up in the rear face piping or otherwise failed to reach the water. None of such fuel elements have caught fire or burned. However, as power levels and exposures are increased, the increased rate of heat generation due to fission product decay energy will increase the potential for melting aluminum jackets and oxidation of uranium. This potential has been decreased by the development and installation of equipment to direct the fuel into the water filled discharge chute in a more positive fashion.

It is possible, but highly improbable, that due to some combination of faulty equipment and operator error one or more process columns of fuel elements could be discharged onto the rear elevator platform.

In each of the incidents above, the application of the rear face fog spray - which is now installed and operable - would provide significant cooling. The "fog" nozzles provide a wide range of droplet size, with a total downpour of about one-half inch of water per minute falling on a horizontal surface.

Although the fog spray cannot prevent burning of a few grams of highly pyrophoric material, such as uranium hydride, which appears to be characteristic of the fires associated with the discharge of ruptured fuel, the rainout provided is very effective in removing the contaminating fission products (particulates and volatiles) from the air. In a recent incident of this nature (Appendix) the fog spray was turned on prior to the discharge of a ruptured fuel element. The element was observed to burn during the discharge but no radioactive contamination was detected beyond the immediate rear face area.

There is a remote possibility of irradiated fuel elements becoming exposed to the air at the front of the reactor. Such an event could occur if initiated by failure of a front nozzle assembly in such a way as to provide free exit to the fuel elements, combined with the explosive formation of steam within the process tube to provide the driving force to expel the fuel. No such mechanical failures have occurred, and it is improbable that steam would be formed at an explosive rate. Improved nozzle designs are currently being evaluated, in connection with other programs, which would further reduce the probability of such mechanical failure. In the event, however, that

irradiated fuel elements were expelled into the front face work area, and if they then heated to the ignition point, the released fission products would be directed by the ventilation air stream to the filter building.

8.2.2 Inadequate Cooling Within the Reactor

Complete loss of coolant to a production reactor would result in massive uranium melting. Such a meltdown is not a credible accident unless caused by another disastrous incident such as severe earthquake, extended flow stoppage of the Columbia river, act of war, high flood or falling object (such as a meteor).

Partial coolant loss could result in fuel melting within a reactor. Loss of coolant to a single process tube could result from a supply fitting failure, or from tube plugging. Loss of coolant to several process tubes could result from front face piping rupture or from gross procedural violations during preparation for discharge operations.

8.2.3 Fission Product Release Potential

The fission product release to the reactor building resulting from melting of irradiated fuel within the reactor block would be much less than the inventory of fission products available in the fuel. The fission products would escape to the building through the reactor gas channels unless the front or rear coolant water piping and fitting had been breached. It is expected that essentially all of the particulate matter and most of the halogens would be retained within the graphite block or plated out on gas passages for single or few tube incidents. This idea is supported by the observation that severe fuel and tube ruptures have resulted in washing significant fractions of a fuel element into the graphite stack without causing a detectable increase in the reactivity of the reactor gas effluent from the reactor. (A mixture of helium and carbon-dioxide is passed through the graphite stack, monitored, purified, and recirculated through the reactor.) Very pessimistic release factors have been used in estimating consequences of fission product release incidents.

The release of fission products from fuel elements burning on the rear face would approach the values indicated in section 8.1. However, the fog spray would be expected to carry most of these fission products into the storage basin where they could be immobilized and subject to disposal as required. This expectation is supported by the observation that the fog spray is very effective in preventing the spread of air-borne fission products released in the rear face area. On one occasion a ruptured fuel element was observed to burn for a few seconds during discharge while the fog spray was in operation. No contamination was observed in the air exhaust ducts after this incident, (Appendix). Similar incidents without the fog spray had resulted in marked contamination of these ducts.

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Thus, the radioactive fission products reaching the reactor building air exhaust ducts from fuel elements melting inside the reactor, or oxidizing in the discharge area would consist primarily of the noble gas fraction. Loss of a front fitting on a process tube could result in inadequate reverse-flow cooling. The steam generated could carry uranium oxide plus fission products into the front face work area without significant retention. These fission products would be directed toward the air exhaust ducts to the confinement filters by controlled airflow.

8.3 Fission Product Release Models

The quantity and nature of the fission products which would reach the top of the air exhaust chimney stack provided for each reactor is very sensitive to the nature of the incident causing the release and to the physical environment.

It is not possible to describe quantitatively the percentages of selected radioactive species which would be retained in the graphite, for example, removed by a fog spray, or deposited on concrete surfaces prior to reaching the filters. Consequently a gross model which is expected to overestimate the release is used.

The fission product model used assumes that 25% of the gross inventory is released from the reactor into the building. This is fractionated as

100% of the noble gases
70% of the halogens
10% of the remainder

No reduction of fission products due to fog spray or deposition within the building prior to reaching the filters has been assumed.

For comparison, the fission product release model adopted by the Risk Evaluations Subcouncil of the General Electric Reactor Safeguards Council is presented.⁽¹⁷⁾ This model represents the worst conceivable release from a contained water-cooled reactor in which the fuel does not vaporize during a full pile meltdown.

	<u>Revised (June 1959)</u> <u>Percent Released</u>	<u>Old (June 1958)</u> <u>Percent Released</u>
Noble Gases	50	100
Iodine and Bromine	12.5	70
Cs, Te, Se, Ru	7.5	10
All Others	0.15	10

Factors used for accounting for plating out on the pressure vessel and containment sphere are as follows:

(Adopted June 1959)
Percent Released (Not Deposited)

Noble Gases	100
Iodine and Bromine	50
Cs, Se, Te, Ru	30
All Others	20

Although the Hanford reactor buildings are not strictly comparable to a pressure sphere the plating out factors should be similar.

8.4 Calculated Consequences

The calculated consequences of an accident - without confinement - have been evaluated by J. W. Healy.⁽⁸⁾ Rogers and Heacock⁽¹⁰⁾ have modified Healy's results to take into account the effects of filtration and halogen absorption assuming 50% halogen retention instead of the 95% retention measured using the activated charcoal absorbers developed for this confinement system. Their conclusions are summarized in Tables 8-2 through 8-5. These conclusions are authoritative and have not been superseded. Although the release factors are believed to be pessimistically large, the meteorological uncertainties make the estimated areas and distances affected relatively insensitive to the fission product release model.

It should not be inferred that inclusion of a full reactor meltdown case in these calculated consequences implies that the confinement system would remain fully effective during a full reactor meltdown. Although tests have shown that the halogen collectors (activated charcoal) could retain the halogen inventory of a reactor without significant loss of efficiency, the over-all efficiency of the confinement system during a hypothetical full reactor meltdown would be very sensitive to the cause of the meltdown. A full reactor meltdown would require major loss of coolant, which would probably be caused by a catastrophically violent event such as an earthquake. Loss of all pumping power would mean loss of the fog spray, and probably loss of fan power. A violent causative agent would probably destroy other components of the reactor complex and render the confinement ineffective independent of the loss of power.

Thus, the full pile meltdown is used only as a basis for evaluating the relative effectiveness of the confinement system.

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TABLE 8-2

FISSION PRODUCT RELEASE FROM EXHAUST STACK*

<u>Quantity of Fuel</u>	<u>Total Inventory (Curies)</u>	<u>Release to Stack (Curies)</u>	<u>Noble Gases (Curies)</u>	<u>Halogens (Curies)</u>	<u>Particulates (Curies)</u>
<u>Without Confinement</u>					
1 tube	4×10^6	1×10^6	4×10^5	3×10^5	3×10^5
4 tubes	1.6×10^7	4×10^6	1.6×10^6	1.1×10^6	1.3×10^6
150 tubes	6×10^8	1.5×10^8	6×10^7	4×10^7	5×10^7
Reactor	6×10^9	1.5×10^9	6×10^8	4×10^8	5×10^8
<u>With Confinement</u> (.001 release factor for particulates; .5 release factor for halogens)					
1 tube	4×10^6	5.5×10^5	4×10^5	1.5×10^5	3×10^2
4 tubes	1.6×10^7	2.1×10^6	1.6×10^6	$.5 \times 10^6$	1.3×10^3
150 tubes	6×10^8	8×10^7	6×10^7	2×10^7	5×10^4
Reactor	6×10^9	8×10^8	6×10^8	2×10^8	5×10^5

*Based upon 2000 MW reactor, all fuel at maximum exposure and negligible decay time after shutdown. No depletion due to fog spray or building deposition is assumed.

TABLE 8-3
MAXIMUM DISTANCES (MILES) FOR RELEASE FROM STACK

<u>Incident</u>	<u>Without Confinement</u>		<u>With Confinement</u>	
	<u>Stable</u>	<u>Unstable</u>	<u>Inversion</u> <u>(Stable)</u>	<u>Neutral</u>
<u>Full Reactor</u>				
Long Evacuation	0-500	20-40	4	-
Temporary Evacuation	>200	70-150	20	10
Crop Confiscation	>200	>300	80	100
<u>One Tube</u>				
Long Evacuation	<1	<1		
Temporary Evacuation	<1	1-3		
Crops (Particulates)	0-40	4-10		
(Halogens)	<200	70-200		

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TABLE 8-4

ESTIMATED AREAS AFFECTED BY STACK RELEASE (SQUARE MILES)

<u>Incident</u>	<u>Without Confinement</u>		<u>With Confinement</u>	
	<u>Stable</u>	<u>Unstable</u>	<u>Inversion</u> (Stable)	<u>Neutral</u>
<u>Full Reactor</u>				
Long Evacuation	>1000	20-40	<1	<1
Temporary Evacuation	>1000	300-400	10	7
Crop Confiscation	>1000	>1000	100	500
<u>One Tube</u>				
Long Evacuation	<1	<1		
Temporary Evacuation	<1	<1		
Crops (Particulates)	0-10	2-3		
(Halogens)	>200	>200		

TABLE 8-5

PERSONNEL DOSE FROM NOBLE GAS RELEASE
(at 10 miles from reactor)

<u>Incident</u>	<u>Unstable</u>	<u>Stable</u>
4 tubes	- - - -	< 1 rad
150 tubes	< 1 rad	15-90 rad
Full Reactor	1-8 rad	200-1000 rad

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9. ACKNOWLEDGEMENT

This report summarizes work done by many people, most of whom are recognized in the Bibliography. The author takes pleasure in recognizing the assistance provided by G. E. Zima who assembled the material in section 8.1 on fission product release mechanisms, C. E. Jones who provided the figures, and by H. W. Heacock who has critically reviewed this document.

A handwritten signature in dark ink, appearing to read 'R. E. Trumble', with a long horizontal flourish extending to the right.

R. E. Trumble, Supervisor
Reactor Engineering Unit
RESEARCH AND ENGINEERING

RET:vb

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FIGURE 1
FACILITY LAYOUT

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FIGURE II
FOG SPRAY SYSTEM

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FIGURE III
FILTER BUILDING

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TYPICAL FILTER BANK ARRANGEMENT

FIGURE 1V

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TYPICAL FLOW DIAGRAM

FIGURE V1

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APPENDIX

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Reactor Engineering Unit

NEAR FACE CONTAMINATION INCIDENTS
105-KW, JULY 6, 1960, 12:17 P.M.

A rupture was being pushed from tube 3974-KW using above normal force and a single spray nozzle directed on the rupture discharge nozzle. Some dark crud was observed emerging from the rupture tube just prior to the appearance of the ruptured fuel element. The full discharge area fog spray was turned on and removal operations resumed. When the ruptured element emerged it was observed to "burn like a stick of wood" from the time it left the tube until it hit the storage basin. The observation was made through the viewing window by W. J. Cartin and others.

From other measurements it is estimated that it takes about 1 to 1.5 seconds for a fuel element to fall this distance.

Radiological Effects

1. Kanne chamber monitor of discharge area exhaust air (a gas monitor, not a measure of particulates): Increased 4 to 5 major division and remained at that level.
2. Dose rates from exhaust duct work: No change.
3. Ground survey to determine particulate deposition: Two particles found outside exclusion area, neither particle originated from this incident.
4. Storage basin water: Dose rate increased to 10 mr/hour at pickup chute rail from a normal dose rate of 1 to 2 mr/hour.
5. Filter monitor of 105-KW exhaust air: Integrated release 0.08 curies; pre-dominant activity due to Te¹³² and I¹³².
6. Contamination spread in discharge area: No change.

Editorial Comment:

The beneficial effects of the fog spray exceeded my most extravagant hopes. By comparison with a similar occurrence (HW-63076, "105-KW Uranium Fire, April 29, 1959") it would appear that the stack release was a factor of 10 to 20 less than would have been expected without the fog spray and that only gases plus tellurium and iodine escaped in significant amounts. This, plus the absence of high dose rates within the building, suggests that almost no particulate material escaped.

s/ R. E. Hall
Radiological Engineering Unit
Process & Reactor Development

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