208
6-30
IN-1465

1845

UC-2

SAFETY ANALYSIS REPORT FOR PEACH BOTTOM 1 CORE 1 FUEL STORAGE FACILITY

J. D. Hammond
R. S. P'Pool
R. D. Modrow

MASTER

THIS DOCUMENT CONFIRMED AS
UNCLASSIFIED
DIVISION OF CLASSIFICATION
BY JH/Kahn/amh
DATE 7/14/71

IDAHO NUCLEAR CORPORATION
NATIONAL REACTOR TESTING STATION
IDAHO FALLS, IDAHO 83401

Date Published—June 1971

R0466

PREPARED FOR
U. S. ATOMIC ENERGY COMMISSION
IDAHO OPERATIONS OFFICE
UNDER CONTRACT NO AT(10-1)-1230

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.95

LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

SAFETY ANALYSIS REPORT FOR
PEACH BOTTOM I CORE 1 FUEL STORAGE FACILITY

By

J. D. Hammond
R. S. P'Pool
R. D. Modrow

IDAHO NUCLEAR CORPORATION

A Jointly Owned Subsidiary of

AEROJET GENERAL CORPORATION
ALLIED CHEMICAL CORPORATION
PHILLIPS PETROLEUM COMPANY

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Date Published - June 1971

PREPARED FOR THE U. S. ATOMIC ENERGY COMMISSION
IDAHO OPERATIONS OFFICE
UNDER CONTRACT NO. AT(10-1)-1230

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
[Signature]

.

.

.

.

.

SAFETY ANALYSIS REPORT FOR PEACH BOTTOM I CORE 1 FUEL STORAGE FACILITY

	Page
SUMMARY AND CONCLUSIONS	1
I. INTRODUCTION	2
II. DESCRIPTION OF PEACH BOTTOM I CORE 1 FUEL STORAGE	3
A. Facility Description.	3
B. Fuel Shipment Description	7
C. Fuel Handling and Storage	12
III. SAFETY ANALYSIS	20
A. Nuclear Criticality Safety.	20
B. Radiation Safety During Routine Handling.	20
C. Fuel Temperature Considerations	20
D. Fuel Canister Integrity	22
E. Storage Vault Integrity	22
F. Accident Review	24
IV. REFERENCES.	30
APPENDIX A--SUMMARY OF ASSUMPTIONS AND BASES FOR RADIATION CALCULATIONS.	31
APPENDIX B--SUMMARY OF CRITICALITY STUDIES.	33
APPENDIX C--SUMMARY OF FUEL TEMPERATURE STUDY	36

FIGURES

1. Location of Peach Bottom Storage Facility at ICPP	4
2. Layout of Storage Facility.	5
3. Fuel Storage Vault.	6
4. Peach Bottom Fuel Element	8
5. Section of Fuel Basket and Peach Bottom Transfer Cask	10
6. Peach Bottom Transfer Cask.	11
7. Cask Support Pedestal	13
8. Cask Centering Device	14
9. Lifting Rod Guide	15
10. Lower Lifting Rod	16

FIGURES (Contd.)

	Page
11. Cask Lifting Yoke	18
B-1. Configuration of Fuel During Storage.	34
C-1. Estimated Storage Temperatures of Peach Bottom I Core 1 Fuel. .	39

TABLES

I. Heavy Metal Content of Peach Bottom I Core 1 Fuel	7
II. Summary of Accidents for Storage Facility	25
A-1. Gamma Release Rates for Peach Bottom I Core 1 Fuel.	31

SUMMARY AND CONCLUSIONS

A dry fuel storage facility has been constructed at the Idaho Chemical Processing Plant (ICPP) for storage of the Peach Bottom I Core 1 fuel. The facility consists of 47 underground storage vaults, each capable of storing a shipment of 18 Peach Bottom elements.

This safety analysis shows that the facility is safe for storing the Peach Bottom I Core 1 fuel. Specifically:

1. The facility is designed to provide nuclearly safe storage under maximum reactivity conditions.
2. Handling procedures and equipment permit placement of the fuel in storage with minimal radiation exposure to personnel.
3. The dry, sealed vaults and fuel canisters provide more than adequate fuel containment for long-term storage.

The design basis accident is defined as a handling accident where the fuel basket support system fails during the vault loading operation. This would expose the lower unfueled portion of the fuel elements. However, even for this case, direct exposure of personnel to the fueled portion of the elements would not occur and radiation exposure would be limited to minor doses initially, and some controlled doses during corrective operations. Thus, it is concluded that even this maximum credible accident for the facility does not present unacceptable hazards.

I. INTRODUCTION

In past years, nuclear fuels delivered to the Idaho Chemical Processing Plant (ICPP) were stored under water for relatively short periods of time and then processed to recover the remaining fissionable material. However, the Peach Bottom I Core 1 fuel, the first high-temperature gas-cooled reactor (HTGR) type fuel to be received at ICPP, may be stored for ten years or more before the fuel is processed. In addition, this fuel significantly differs from the metal-clad fuels normally received at ICPP. Therefore, it was necessary to determine the most suitable type of storage for this Peach Bottom fuel.

The Peach Bottom fuel consists of thorium carbide and uranium carbide microspheres coated with pyrolytic carbon and dispersed in a graphite matrix. This fuel must be stored dry because the carbides will react if exposed to water^(1,2), forming hydrocarbons (primarily methane and acetylene) and the metallic oxides of uranium and thorium. The reaction is relatively fast and formation of the metallic oxides can result in volume increases up to 85 percent of the carbide volume in each element. Therefore, each element is sealed inside a fuel canister fabricated of Type 6061 aluminum; an aluminum cap with a double "O" ring seal is used to seal the canister for temporary storage in deionized water at the Peach Bottom reactor site. However, the ICPP fuel storage basin does not employ deionized water; hence, the storage environment at ICPP differs from that at Peach Bottom. Tests conducted at ICPP indicated that the fuel canisters could lose their sealing integrity within one to ten years because of (1) corrosion of the canister in the ICPP fuel storage basin, or (2) consequences of hardening of the "O" ring seals. Leakage of water into the canisters and reaction with the carbides would release fission gases trapped within the fuel. In addition, the accompanying volume expansion as the carbides are converted to oxides could rupture the canisters and release fission products and heavy metals into the surrounding water. Therefore, dry storage in underground vaults was selected as the best method of long-term storage at ICPP. This study establishes that there are no unacceptable safety hazards associated with the dry storage facility.

II. DESCRIPTION OF PEACH BOTTOM I CORE 1 FUEL STORAGE

A. Facility Description

As shown in Figure 1, the fuel storage area is located within the confines of the ICPP security fence and north of CPP-603, the existing fuel storage basin. The storage facility consists of 47 storage vaults spaced on 30-foot centers in a square array and covers an area approximately 200 feet by 350 feet as shown in Figure 2.

The area is sloped for drainage and is graded and filled 1.0 to 1.7 feet above natural ground level with crushed rock and gravel; the surface is suitable for bearing a Manitowoc Model 3900 crawler crane and the truck-trailer unit used to haul the fuel transfer cask to the storage area. Access roads suitable for all-season use are also provided.

Each storage vault is approximately 20 feet deep by 30 inches in diameter (see Figure 3) and accommodates one complete shipment of Peach Bottom I Core 1 fuel. The vaults are lined with carbon steel casing with two feet of sand cement grout at the bottom to seal the vault and provide a base for the fuel. A reinforced concrete pad 8 feet by 14 feet by 1-foot thick is poured around the top of each vault to provide a flat working surface. A temporary cover seals the top of each vault prior to use, preventing water, dirt, and other materials from entering the vaults. After the fuel is inserted into the vaults, top shielding is provided by an off-set, four-foot thick concrete plug. The storage vaults are sealed for containment, security, and inventory control of the spent fuel by welding a steel plate on the top of each vault.

Temperature and humidity data will be collected from each vault by inserting instrument probes through a small access hole in the steel vault cover and through a conduit in the concrete shield plug. (Tentative data collection schedules are presented in Sections III.C and III.F.3) In addition, three vaults are equipped with conduits through the vault wall for measuring wall temperatures. As shown in Figure 3, both the hole in the steel cover and the conduit through the vault wall will remain capped except when data is being collected. An extra vault is provided for experimentation and long-term visual observation.

Fig. 1. Location of Peach Bottom Storage Facility at ICPP.

Fig. 2. Layout of Storage Facility.

Fig. 3. Fuel Storage Vault.

B. Fuel Shipment Description

The fuel storage facility will contain 815 canisters, each containing a Peach Bottom I fuel element with the geometry shown in Figure 4. All components, except the fuel compacts and burnable poison compacts that are placed in the hollow spines of some fuel elements, are made of graphite. The reactor was designed to operate at a full power of 115.5 Mw(t) for 900 days and spent fuel was to be shipped with a minimum cooling time of 120 days. However, the Core 1 fuel received only about 450 equivalent days of full power operation and will have had more than one year cooling time before shipment. The heavy metal content of the fuel is given in Table I.

TABLE I
HEAVY METAL CONTENT OF PEACH BOTTOM I CORE 1 FUEL*

	<u>Before Burnup</u>	<u>900 Days Irradiation</u>
Th-232	1450.0	1390
Pa-233	--	2.76
U-233	--	35.1
U-234	3.5	6.04
U-235	220.0	101
U-236	1.18	26.6
U-238	11.46	9.92
Np-239	--	5.72 g
Pu-239	--	0.35
Pu-240	--	0.08
Pu-241	--	0.16
Pu-242	--	0.06

*In kilograms unless specified otherwise.

All fuel elements are individually sealed in canisters containing an inert helium gas atmosphere. Each canister has a 6061 aluminum alloy outer wall and mild-steel inner liner. The inner liner is 10 feet long by 1/16-inch thick and has an outer diameter of approximately 4.1 inches. The steel liner adds weight to the canisters and prevents them from

Fig. 4. Peach Bottom Fuel Element.

floating in water at the Peach Bottom storage pool. After inserting a fuel element, a magnetic pressing process is used to seal the top of each canister around an aluminum cap having a lifting knob and a double "O" ring seal; this forms an airtight unit with approximate dimensions of 4.5 inches OD by 12 feet 9 inches long and weighing about 150 pounds. The wall thickness is 0.065 inch. The canisters are sealed at atmospheric pressure and helium leak tested before being placed in the storage pool at Peach Bottom. Any leaking fuel element canisters are placed inside salvage canisters of the same construction and configuration except with dimensions approximately 4.75 inches OD by 13 feet 2 inches long.

The canned fuel elements are placed in a basket for shipment inside the transfer cask and for long-term storage at ICPP. The basket is a welded structure of 5-inch ID by 5.25-inch OD 6061-T6 aluminum alloy tubes spaced in concentric circles as shown in Figure 5. One tube is placed at the center with six tubes positioned around it in a circular array; the outermost circular array contains 12 tubes for a total of 19. Aluminum plates, 0.25-inch thick, are welded in the bottom of each tube to support the fuel canisters, between adjacent tubes to strengthen the bundle, and between the outer tubes of the basket to approximate a cylindrical outer surface. A threaded lifting device is welded into the top of the center tube. As constructed, the basket is about 158 inches long, weighs about 920 pounds, and holds 18 canned fuel elements during shipment and storage of the fuel.

The cask (Figures 5 and 6) used to transfer the fuel from Peach Bottom, Pennsylvania, to ICPP has a loaded weight of approximately 62,800 lbs. It has an outer diameter of 42.5 inches, an overall length of 191.12 inches (including impact limiters), and a width across the trunnions of 50.0 inches. The internal cavity is 26.0 inches in diameter and 159.0 inches long. The top end of the cask is equipped with a removable stepped plug; this provides access to the lifting device on the fuel basket. The cask is carried horizontally in a structural steel cradle during transport. Four 8.0-inch-diameter lifting and pivoting trunnions are welded to the outer shell of the cask and fit into trunnion sockets on the mounting cradle. These sockets support and secure the cask during shipping and allow rotation of the cask from the horizontal to the vertical position during handling operations.

Fig. 5. Section of Fuel Basket and Peach Bottom Transfer Cask.

Fig. 6. Peach Bottom Transfer Cask.

C. Fuel Handling and Storage

Typical handling procedures are described in the following paragraphs. The use of a Manitowoc Model 3900 crawler crane and a small mobile crane is assumed; however, the usefulness of the small mobile crane will be evaluated during tests of handling procedures.

Upon arrival at ICPP, the pressure in the cask cavity is checked. A gas sample will be drawn from the cask through a filter cartridge; any remaining pressure in the cask will be vented through the filter cartridge to the off-gas system at the fuel storage basin (CPP 603). The gas sample and any particulates collected in the filter cartridge will be thoroughly analyzed to determine whether any fuel canisters have leaked (since the canisters contain a helium atmosphere, helium detection would mean canister leakage). The results of the analyses will aid in determining the extent of contamination control that may be required during unloading operations. However, administrative controls may preclude the acceptance of a fuel shipment if there is sufficient evidence that the fuel canisters or basket assembly have been severely damaged.

The vault is prepared to receive fuel by (1) removing the temporary cover, (2) inspecting the vault to ensure that it is dry, and (3) taking steps necessary to control any contamination from the interior of the cask or from the exterior surfaces of the basket and canisters (plastic sheets spread over the concrete pad and adjacent ground will be used to control contamination). The cask support pedestal is placed on the concrete slab and the cask centering device is positioned on the top of the vault. The pedestal (Figure 7) is a safety support for the cask while personnel remove bolts from the bottom cover. The centering device, shown in Figure 8, centers the cask over the storage vault and provides radiation shielding while lowering the fuel into the vault. The weight of this centering device is about seven tons.

After preparing the vault, the impact limiters are removed from the cask and the cask disconnected from the transport vehicle. The plug is removed from the top end of the cask and the rod guide (Figure 9) and lower lifting rod (Figure 10) are installed. In addition to their primary functions associated with guiding and lowering the basket of fuel,

Fig. 7. Cask Support Pedestal.

Fig. 8. Cask Centering Device.

Fig. 9. Lifting Rod Guide.

Fig.10. Lower Lifting Rod.

these devices provide a means of supporting the fuel basket inside the cask after the bottom cover is removed. Calculations^(a) indicate that the direct beam of radiation at the center top of the cask with the plug removed could be about 6.1 R/hr. However, the beam is collimated and radiation will be negligible at a distance of one foot to the side of the beam. The lifting yoke (Figure 11) is connected, and the cask is lifted free of the truck and positioned on the support pedestal. After removing the bottom cover, the cask is maneuvered into the centering device over the storage vault. A man standing ten feet from the centerline of the cask might receive radiation at a rate of about 65 mR/hr. A dose rate of about 725 mR/hr might be possible if a man walked up to the edge of the concrete slab while the cask was in a raised position.

The cask is secured over the vault, a long upper lifting rod is attached to the lower lifting rod, and the crane is used to lower the fuel basket into the vault. After placing the fuel in storage, the cask and centering device are removed from over the vault, and the concrete shield plug is lowered into the vault. If the small mobile crane is used for placing the shield plug, a dose rate of about 3.1 mR/hr is estimated for the crane operator due to radiation "shine". Administrative procedures will require personnel to stand at least five feet from the vault opening until the shield plug has been installed. This will prevent exposure to the direct beam of radiation from the fuel, which might be about 150 R/hr.

Once the shield plug is in place, the permanent cover is welded over the top of the vault and the cask is reassembled, decontaminated as necessary, and returned to Peach Bottom. The radiation dose rate through the concrete plug is conservatively estimated at 0.075 mR/hr. Fuel could be retrieved from the vaults, as necessary, by using procedures that are the reverse of those described; however, retrieval would require purchasing a new cask or using the Peach Bottom cask.

Detailed operating procedures have been prepared based on the general procedures given above. These detailed procedures will be tested using

(a) The general bases and assumptions used in all radiation calculations are summarized in Appendix A.

Fig. 11. Cask Lifting Yoke .

a non-radioactive mockup of a Peach Bottom fuel shipment; this will demonstrate the procedures without the risk of radiation exposure to personnel. Spent Peach Bottom fuel will be placed into the storage facility only after the detailed operating procedures have been tested, revised (as necessary), and approved by the appropriate organizations.

III. SAFETY ANALYSIS

A. Nuclear Criticality Safety

Each basket of Peach Bottom I Core 1 fuel will be stored in a completely separate vault and in the same configuration and containers as shipped. Furthermore, the basket assembly will be loaded into the cask under water at the Peach Bottom facility and actual handling will have proven each shipment critically safe before it has arrived at ICPP. However, an independent study was conducted at ICPP to guarantee nuclear criticality safety during storage. This study is summarized in Appendix B.

The highest effective multiplication factor ($k_{\text{eff}} = 0.877$) was obtained by assuming a flooded basket array with the fuel and water theoretically homogenized. Homogenizing the fuel and water gives a highly conservative result and shows that the fuel is safely subcritical.

B. Radiation Safety During Routine Handling

A review of the procedures presented in Section II-C shows that potential radiation hazards will exist. Radiation fields resulting in dose rates as high as 6 R/hr may be encountered. However, doses to personnel can be maintained below radiation protection guide levels through careful monitoring by health-physicists and by adhering to the detailed operating procedures. Thus, the fuel can be placed in storage without unacceptable hazards.

C. Fuel Temperature Considerations

Because the soil surrounding each vault is a poor heat conductor, a study was made to estimate the maximum temperature that the stored fuel may reach. Temperature distributions in the soil were calculated based on previous work performed at ICPP concerning buried heat sources⁽³⁾. The mathematical relationships and assumptions used to calculate the temperatures are described in Appendix C. Various heat generation rates, source sizes, and thermal conductivities were assumed to (1) establish the sensitivity of the calculated temperatures to these key factors, and (2) provide temperature estimates as a function of fuel cooling time. A highly conservative estimate of the temperature differential within the fuel array was made based on calculations by Battelle Memorial Institute

(BMI)⁽⁴⁾. This differential was then added to the vault wall temperature obtained from the soil calculations mentioned above. This resulted in a conservative estimate of the maximum temperature within a fuel array.

Based on a minimum fuel cooling time of 150 days, the temperature of the fuel might approach 700°F in a storage vault. However, the Core 1 fuel was removed from the reactor in October 1969, and will have had in excess of one year of cooling time when it is placed in storage. Assuming one year of cooling time, the calculations indicate the fuel might reach a maximum temperature of about 500°F. However, this temperature will not cause any hazardous conditions. The lowest temperature at which combustion of the graphite could occur is 1100°F and graphite oxidation is negligible at temperatures below 750°F. In addition, fission product diffusion from the fuel elements is negligible at the estimated storage temperatures.

The maximum estimated temperature of the fuel is well below any temperature limitations. Effectively, the cooling time of the fuel controls the storage temperature; therefore, there is no need for a temperature alarm system or any method of controlling temperatures within the vaults. However, vault temperature data will be taken periodically to verify the calculations for any future design of a similar facility. As mentioned in Section II.A, each vault is equipped with a conduit through the shield plug for collecting data. In addition, three vaults are equipped with conduits to provide instrument access for measuring vault wall temperatures. Thermocouples will be inserted through these conduits and portable instruments will be used to measure the temperatures.

Tentatively, temperature data will be collected daily from each of the first few shipments of spent fuel that are placed in storage vaults. This will establish the initial temperature response of a vault. As conditions within each of these vaults reach equilibrium, data will be collected less frequently and a routine data collection schedule will be initiated. This routine schedule will probably specify data collection on a bimonthly or monthly basis; however, the frequency will be dictated by the results of the collected data. Other storage vaults may be added to this routine schedule as they are filled with spent fuel; but the temperature data will probably be collected only from a few representative vaults.

D. Fuel Canister Integrity

1. Exposure to Water

The fuel canisters were designed for storage in deionized water, and their prolonged exposure to non-deionized water should be avoided. This conclusion is supported by results of tests showing that the fuel canisters suffer pitting corrosion in the ICPP basin water. Short-term storage in the basin might be allowable, but the corrosion rate of the canisters is unacceptable for long-term storage in the basin. Storing the canisters dry prevents them from corroding; thus, the canisters are preserved to provide short-term or, at least, emergency protection against water.

2. Effects of Gamma Radiation and High Temperature

High temperatures and gamma radiation are known to have detrimental effects on most gasket and seal materials. The Buna N-4387 "O" rings used to seal the Peach Bottom fuel canisters were tested to determine the reliability of the seals after exposure to heat and radiation. Heating an "O" ring of the same material in air at 350°F for one week caused the seal to harden. Irradiation in the MTR Gamma Facility revealed that about 1×10^9 roentgen (R) also caused hardening. Based on these results, it is believed that temperature, rather than radiation, could cause the Peach Bottom canister seals to harden. Hardening of the rings, in itself, would not necessarily cause loss of sealing integrity; however, it could result in loss of sealing if the top of any canister were deformed. Except in rare cases of severe damage where recanning is necessary, this loss of sealing would result in nothing more than "pin-hole-type" diffusion through very small cracks in the seals. Thus, the seals will be adequate to prevent gross particulate contamination within the vaults (from gas leakage), and will provide at least temporary protection against in-leakage of water in emergency situations.

E. Storage Vault Integrity

1. Effect of Ground Water

The soil in the storage area is primarily sand and gravel and provides very good drainage. Under normal conditions, decay heat from

the fuel will further reduce the moisture content in the soil adjacent to the casings. In extreme situations, the subsoil may become temporarily saturated with water because of broken water pipes, heavy rains, or sudden thaws. However, the vaults are designed to keep out ground water. The joint between the two casings making up each vault, shown in Figure 3, is provided with a bentonite-soil mixture (water seal). The bottom of each vault is filled with two feet of sand-cement grout. Although grout shrinkage may leave a small gap between the grout and the casing, the bottom of the vault will remain sealed for all practical purposes; that is, a very large pressure differential would be required to force water into the vault. Since there is no known mechanism for producing such a pressure difference, it is highly improbable that water could seep into the vaults. It would also be highly unlikely that steam, if produced, would penetrate the vaults; the temperature gradient in the soil will establish a driving force to transport moisture away from the vault casings.

Because of the normally dry condition of the soil, corrosion of the vault casings will be almost negligible. Well casings at ICPP have shown essentially no exterior corrosion from soil moisture after being exposed for more than 15 years. Combining this very low corrosion rate with the 0.28-inch thickness of the vault casings, it is estimated that the casings will have a useful life of more than fifty years. Thus, ground water should have no effect on the integrity of the vaults during storage.

2. Effect of Floods

The ICPP is located within the Big Lost River Valley. Therefore, the maximum credible flood for the ICPP would result from failure of the Mackay Dam on the Big Lost River. This would release about 44,000 acre feet of water. Downstream from the dam, the river flows through a narrow canyon (called Box Canyon) before reaching that portion of the valley where the ICPP is located. Assuming weir flow in the canyon, the maximum flow rate into this portion of the valley would be about 7,400 cubic feet/second. Because this portion of the valley is about one mile wide, this flow rate might produce a maximum water depth of about seven inches.

Since the above analysis was made, drainage and flood control projects have been completed which essentially eliminate the possibility that a flood could affect the ICPP area. However, provisions were made in the design of the storage facility to ensure that water would not reach the fuel. The entire storage area is backfilled with crushed rock and gravel to a height of 1.0 to 1.7 feet above the natural ground level. A one-foot-thick concrete pad is poured around each vault on top of the gravel surface. In addition, the casing for each vault extends six inches above the concrete pad and a carbon-steel plate will be welded over the top of each vault to seal out water. Because the top of each vault is sealed and is at least 2.5 feet above natural ground level, the flooding conditions described above should not cause leakage of water into the storage vaults.

3. Effect of Earthquakes

Damage from earthquakes results from differential movement in a structure. Because each vault is independent of the other storage vaults, the facility is characterized by numerous small structures rather than a single large structure. The compact size of each vault and the materials of construction make it improbable that enough differential force could be exerted to rupture a vault. It may be possible to crack the seal between the two casings making up each vault, but the bentonite mixture used to seal the casings is "self healing" upon contact with water and will reseal the vault. Thus, it is highly improbable that an earthquake would have any effect on the integrity of the storage vaults.

F. Accident Review

A review of the facility and procedures for placing the fuel in storage reveals that there are three types of accidents that may be considered for the facility. These accidents are described below and summarized in Table II.

1. Nuclear Criticality

Because the facility involves the storage of fissile material, the possibility of a nuclear criticality was examined. The examinations were independently reviewed by the Nuclear and Operational Safety

TABLE II
SUMMARY OF ACCIDENTS FOR STORAGE FACILITY

<u>Abnormal Event</u>	<u>Mechanism</u>	<u>Detection</u>	<u>Prevention</u>	<u>Control</u>	<u>Consequences</u>	<u>Likelihood</u>
Nuclear Criticality	--	--	- Critically safe design	--	--	Impossible
Drop Fuel Basket	- Failure of basket support mechanism	- Visual	- Thorough inspection of support mechanism - Careful handling	- Necessary precautions against contamination - Limiting exposure of personnel	- Irradiation of operating personnel	Possible
Fission Product Release	- Leaching by water and seepage from vault	- Periodic Sampling	- Fission product decay heat - Sealed system	- Remove fuel from vault	- Contamination of subsoil surrounding vault	Improbable
	- Airborne particulate contamination escaping from vault	- Periodic Sampling	- Sealed system	- Filter vault air	- Small amount of airborne contamination around storage facility	Improbable
	- Over pressurization of vault by water flashing to steam	--	- Sealed system	--	--	Highly Improbable

Division and showed that the canned fuel will be safety subcritical in all cases; therefore, nuclear criticality is not credible.

2. Radiation Exposure

The project involves the handling of irradiated material; therefore, potential radiation hazards do exist. Techniques based on established handling procedures will permit safe transfer of the fuel under normal circumstances. However, unusual situations could occur. The components of the fuel basket support mechanism are designed to support at least three times the maximum weight of the loaded fuel basket with no yield⁽⁴⁾, so it is improbable that the support mechanism could fail. But, for the sake of this analysis, three cases are postulated where the basket support mechanism fails:

1. While lifting the cask free of the bottom cover.
2. While moving the cask from the support pedestal to the centering device.
3. While lowering the fuel into the storage vault.

Failure in Case 1 would drop the fuel basket onto the bottom cover. The cask could be lowered back over the fuel with only minor accidental radiation exposure to personnel. Subsequent corrections would be made under controlled conditions.

Failure of the basket support mechanism while moving the cask from the support pedestal to the centering device (Case 2) could present the most serious situation of the three cases. To be positioned on the centering device, the cask must be lifted clear of the bottom cover and moved into position above the centering device. The support pedestal is immediately adjacent to the centering device so that the cask is always above these items during the operation. If the basket support mechanism should fail, the fuel basket would drop onto the edge of the centering device or the edge of the cask support pedestal, and circumstances might prevent immediately lowering the cask to cover the exposed section of the fuel basket. However, the fuel basket cannot drop out of the cask far enough to allow direct exposure of the fueled portion of the elements unless the cask is lifted

to more than 26 inches above the centering device or pedestal. Since the cask will be lifted only enough to clear the support pedestal and centering device, it is unlikely that the fuel basket could drop sufficiently to expose the fueled portion of the elements. To estimate the magnitude of radiation dose rates, an accident was assumed where 20 inches of the fuel basket was exposed; dose rates at about 7 feet from the outer surface of the fuel basket might be about 25 R/hr. Thus, operating personnel will not receive large uncontrolled doses of radiation. The method of recovering a dropped fuel basket would depend upon the circumstances involved and radiation exposure to personnel would be carefully controlled during the recovery operation.

Failure in Case 3 could allow the basket of fuel to drop as much as twenty feet into the storage vault. The basket and/or fuel canisters may be damaged but the fuel array would be contained within the vault and shielded from personnel. The fuel would have to be retrieved and inspected for damage, but this would involve only controlled radiation exposure to personnel.

Since Case 2 would involve both controlled exposure and minor accidental doses of radiation to operating personnel, it would be more serious than Cases 1 and 3. However, none of the handling accidents described above will present any unacceptable conditions.

3. Release of Radioactivity

The possibility of release of radioactive material to the environment was also considered. The fuel elements, as received and stored, are encased in aluminum canisters and enclosed in the storage vaults. Leakage of the fuel canister seals, although unlikely, would be no more than a matter of "pin-hole-type" diffusion. Because of the lack of a significant driving force (such as a gas flow over the surface of the elements within the canisters), it is improbable that a significant amount of contamination could become airborne, diffuse out of the canisters, and escape from the vaults. If water contacted the fuel and reacted with the carbide particles, it is possible that krypton-85 could be released to the vault atmosphere, and that fission products could be slowly leached from inside the vaults and deposited in the surrounding soil. However, as described in Sections III.D and

III.E, it is highly improbable that moisture will penetrate both the vaults and the canisters.

Because of the estimated temperatures of the stored fuel, flash vaporization of water within the vaults is possible under abnormal conditions. Therefore, fission product release by overpressurizing the vaults and/or fuel canisters was considered. The fuel canisters are designed for an external pressure of 15 psig and would be the limiting factor in pressure considerations. The storage vaults were not designed as pressure vessels and will not maintain a pressure differential for any length of time; therefore, instantaneous flashing of water inside the vaults would be required to pressurize them. Neglecting any internal pressure in the fuel canisters because of temperature, it would be necessary to add, instantaneously, about 0.9 gallons of water to obtain a flash pressure of 15 psig in the vault. However, a mechanism could not be identified which could add this amount of water instantaneously without inherently providing a mechanism for release of any pressure developed. Furthermore, as described in Section III.E, it is improbable that moisture will penetrate the vaults.

Thus, from the information already presented, an important fact becomes apparent: If hazardous conditions do develop within a storage vault, they will develop slowly. That is, water seepage and canister corrosion must continue undetected for weeks, or probably months, before the water could contact the fuel. Likewise, gas diffusion through the small cracks in a canister seal would require considerable time to create a significant contamination problem within a storage vault. Therefore, periodic checks of the storage facility will reveal any water seepage or airborne activity before significant hazards develop. Gas samples will be drawn from the vaults using an evacuated sample bomb and then analyzed in the ICPP Analytical Laboratory. Equipment in the analytical laboratory is continually used for samples important to plant operations and is, therefore, checked routinely to assure accurate analytical results. Moisture will be detected by using a portable psychrometer to determine the humidity in the vaults. The psychrometer can be easily checked before each use by verifying ambient air conditions.

A gas sample will be drawn from each vault about two weeks after it has been filled with fuel and sealed. Thereafter, the frequency of sampling each vault will be adjusted based on its data record. Thus, some vaults may be sampled quarterly, while others are sampled monthly or even weekly to ensure safe storage. If the air samples from any vault contain abnormally high or unexpected amounts of contaminants (including krypton-85), it may be necessary to remove the fuel for inspection and recanning.

Humidity data will be collected on a schedule similar to that of temperature data. That is, data will be collected daily from the first few shipments of fuel that are placed in storage and a routine data collection schedule will be initiated after sufficient transient data has been collected. The frequency of data collection will then be established based on the data record for each vault. This data may be collected monthly, bimonthly, or on some other schedule as necessary to ensure safe storage. If an abnormally high or unexpected amount of moisture is detected, it may be necessary to remove the fuel from a vault for inspection.

In addition to the collected data (gas compositions, humidity data, and temperature data), one spare vault without any fuel will be maintained to provide a visual observation of the "worst case" for any water seepage. By so doing all of this, any hazardous conditions will be identified in time to prevent serious consequences. Thus, it is improbable that the facility will pose any threat to the environment.

4. Summary

Although a nuclear criticality would be the most serious accident conceivable (considering both off-site and on-site personnel, and the environment), it is impossible. A fission product release during storage would have some effect on the environment; however, it is improbable that a mechanism for release of fission products will develop and, furthermore, periodic checks would reveal the presence of any problems before significant releases could occur. A handling accident would expose operating personnel to minor accidental doses of radiation. Because the possibility of a handling accident is contingent upon human error and/or structural failure, it is more credible than the other postulated accidents, and is therefore deemed the design basis accident. However, such an accident will not result in unacceptable consequences.

IV. REFERENCES

1. R. D. Burnette, Hydrolysis of Uranium and Thorium Carbides, GAMD-9670 (October 1969).
2. N. G. Schmahl, On Carbide Hydrolysis, N70-20774 (March 1970).
3. D. E. Black and B. R. Dickey, Mathematical and Experimental Analysis of Heat Dissipation from Cylindrical Sources Buried in Soil, IN-1032 (December 1966).
4. Battelle Memorial Institute, Safety Analysis for the Shipment of Peach Bottom No. 1 Irradiated Fuel Elements in Whitehead and Kales Shipping Cask Model No. PB-1 (January 1970) pp. 52-65.
5. W. E. Selph, Neutron and Gamma-Ray Albedos, ORNL-RSIC-21 (February 1968).
6. G. E. Hansen and W. H. Roach, Six- and Sixteen-Group Cross Sections for Fast and Intermediate Critical Assemblies, LAMS-2543 (1961).

APPENDIX A

SUMMARY OF ASSUMPTIONS AND BASES FOR RADIATION CALCULATIONS

Radiation calculations were based on techniques that are routinely used for radiation analyses at the National Reactor Testing Station. To be conservative, the fuel was assumed to have had 900 days of full power irradiation and to have only 120 days of cooling time. The gamma release rates estimated by Battelle Memorial Institute⁽⁴⁾ and used as a basis for the calculations are presented in 12 energy groups in Table A-1.

TABLE A-1
GAMMA RELEASE RATES FOR PEACH BOTTOM I CORE 1 FUEL*

Group	Energy Range (Mev)	Average Energy (Mev)	Group Energy (Mev/sec)
1	0.1-0.4	0.3	4.536×10^{15}
2	0.4-0.9	0.63	2.399×10^{15}
3	0.9-1.35	1.10	1.414×10^{15}
4	1.35-1.8	1.55	1.226×10^{14}
5	1.8-2.2	1.99	1.739×10^{13}
6	2.2-2.6	2.38	4.190×10^{13}
7	2.6-3.0	2.75	8.276×10^{12}
8	3.0-3.5	3.25	1.587×10^{12}
9	3.5-4.0	3.70	0.796×10^{12}
10	4.0-4.5	4.25	0
11	4.5-5.0	4.70	0
12	5.0-5.5	5.25	0

*Per shipment of 18 fuel elements.

All calculations were based on the circular fuel array containing 18 elements described previously, and the assumption that all gamma radiation originated within the 90-inch fueled section of the elements (see Figure 4). Attenuation of gamma rays within the fuel elements was considered in addition to the obvious shielding benefits (eg, the cask,

centering device, concrete plug, etc.). However, any shielding benefit from the aluminum basket and fuel canisters was ignored. Scattering calculations were based on published⁽⁵⁾ gamma-ray albedos^(a).

It was recognized that radiation dose rates vary with distance; for instance, while lifting the cask free of the bottom cover, radiation fields will increase as the cask is lifted higher. Therefore, the distance parameters described in this report were selected to be representative of each portion of the overall operation. A more thorough analysis is not warranted since all radiation exposure will be strictly controlled by detailed operating procedures and health physicists. However, the calculations do provide conservative estimates of the radiation fields that are to be expected.

(a) A term describing the radiation scattering property of a material; the ratio of reflected to incident radiation.

APPENDIX B
SUMMARY OF CRITICALITY STUDIES

Nuclear criticality safety of the Peach Bottom I Core 1 fuel storage facility was examined using the SCAMP computer code^(a) with Hansen-Roach cross sections⁽⁶⁾. In all cases, it was assumed that the fuel array had infinite height and that the fuel had no burnup. Most of the cases also assume a circular array of 19 canned fuel elements as shown in Figure B-1. The assumed cases and the effective multiplication factor (k_{eff}) for each are as follow:

- Case 1: Circular array of 19 canned elements packed tightly together with $d_1 = 4.5$ inches and $d_2 = 21.8$ inches; water fully flooding the array both inside and outside the canisters with a 25 cm water reflector around the array. $k_{eff} = 0.684$.
- Case 2: Circular array similar to Case 1; water flooding the array outside the canisters with a 25 cm water reflector around the array. $k_{eff} = 0.637$.
- Case 3: Circular array similar to Case 1; no water present. $k_{eff} = 0.031$.
- Case 4: Circular array similar to Case 1; a dry array with 23 cm water reflector. $k_{eff} = 0.323$.
- Case 5: An infinite array of canned elements tightly packed together; the array flooded with water both inside and outside the storage canisters. $k_{eff} = 0.738$.
- Case 6: Circular array of 19 canned fuel elements inserted in the basket assembly with $d_1 = 5.25$ inches and $d_2 = 25.56$ inches; water fully flooding the array both inside and outside the canisters with an infinite water reflector. $k_{eff} = 0.784$. (The value of k_{eff} for Case 6 is higher than Cases 1 through 5 because of the increased effect of moderation by water within the array.)

(a) A criticality code used at the NRTS, Idaho.

Fig. B-1 Configuration of Fuel During Storage

Case 7: Circular array similar to Case 6; water flooding the array outside the canisters with an infinite water reflector and the water within the array theoretically homogenized with the fuel. $k_{\text{eff}} = 0.877$.

APPENDIX C
SUMMARY OF FUEL TEMPERATURE STUDY

For buried cylindrical heat sources, the calculation of temperatures in the soil involves the solution of a boundary value problem by finite sine transformation⁽³⁾. The relative steady state temperatures in the soil are given by the following equation:

$$T_s(r, z) = \frac{2L^2 q''}{\pi} \sum_{n=1}^{\infty} \frac{\left[\cos \frac{n\pi d}{L} - \cos \frac{n\pi D}{L} \right] [I_1(X_B) K_0(X)] \sin \frac{n\pi z}{L}}{n^3 [k_c K_0(X_B) I_1(X_B) + k_s K_1(X_B) I_0(X_B)]}$$

Where T_s = temperature of the soil, °F.

r = radial distance from center of heat source, ft.

z = distance below the ground surface, ft.

q'' = the heat generation rate, Btu/hr-ft³.

d, D = depth below the ground surface to the top and bottom of the heat source, respectively, ft.

k_c, k_s = thermal conductivities of material within the vault and the soil, respectively, Btu/hr-ft-°F.

$I_0(X), I_1(X)$ = modified Bessel functions of the first kind of the zero and first order, respectively, for argument X .

$K_0(X), K_1(X)$ = modified Bessel functions of the second kind of the zero and first order, respectively, for argument X .

$X = \frac{rn\pi}{L}$ (dimensionless).

X_B = X evaluated at the radius of the heat source (dimensionless).

L = that depth (ft) in the axial (z) direction at which an increase ΔL , results in a negligible change in the calculated temperature; found by iteration.

n = an integer (finite sine transform parameter).

The relative temperatures determined from this equation are then added to the ambient temperature of the soil (about 50°F) to obtain the estimated soil temperatures.

Maximum temperatures in the fuel array were estimated by adding the calculated soil temperatures at the storage vault casing to the temperature differential within the vault. Battelle Memorial Institute⁽⁴⁾ (BMI) estimated a maximum fuel temperature of 350°F and a temperature differential

of about 140°F from the center of the fuel array to the inner liner of the Peach Bottom transport cask during shipment of the fuel; BMI assumed a fuel cooling time of about 100 days and a 19 element circular array. The radial dimensions within the storage vault are larger than those inside the transport cask and could increase the temperature differential. However, convection currents will develop inside the vaults to aid in heat transfer and the temperature differential should not be significantly affected. In addition, the fuel will be shipped in an 18 element array (no fuel in the center tube of the basket) and will have a cooling time of more than one year. These differences mean that the heat generation within the fuel array will be less than 20 percent of the heat load used in the BMI calculations. However, to be highly conservative, a temperature differential of 200°F was assumed within the storage vaults, regardless of fuel cooling time.

To make the soil temperature calculations, it was necessary to define an effective heat source. The vault casing is the interface between the actual source and the soil and the soil temperature is affected by the flow of heat across this interface. Therefore, the vault casing was assumed as the radial limit of the heat source. Air gaps in the fuel array provide considerable resistance to the radial flow of heat within the vault; thus, the relative amount of axial heat flow becomes more significant. The thermal conductivity of the vault casing is also much higher than that of the soil. These factors combine to increase the axial heat transfer and, thus, the effective height of the heat source. In addition, the ground surface will behave as a heat sink, making upward heat transfer within the vault more important than downward heat transfer. For the calculations, the effective heat source was assumed to be 16 feet long and 30 inches in diameter. In the equation, d (the depth below the ground surface to the top of the heat source) was assumed equal to three feet and, therefore, D was set at 19 feet.

In addition to those listed above, a number of other assumptions were made. Inherent in the equation is the assumption that a uniform heat generation rate (q'') exists throughout the heat source. The soil thermal conductivity (k_s) was varied from 0.200 to 0.500 Btu/hr-ft-°F, depending on the magnitude of the heat flux and the temperatures calculated. Also

inherent in the equation is the assumption of a uniform value for the thermal conductivity of the material within the vaults (k_c); this was not a valid assumption for this particular system. As mentioned previously, air gaps in the fuel array provide considerable resistance to radial heat transfer. The source size and heat generation rate assumptions described above were made to approximate the importance of axial heat transfer; therefore, it was necessary to assume a small value for k_c to essentially eliminate its effect on axial heat transfer.

Results of calculations based on these assumptions are shown in Figure C-1. The temperatures are believed to be conservative because of two important assumptions:

1. The temperature differential within the fuel array was assumed to be 200°F regardless of fuel cooling time. In reality, the maximum temperature differential should be less than 200°F and will decrease even more as the heat generation in the fuel decreases with time.
2. The fuel was assumed to have had 900 days of equivalent full-power irradiation. As mentioned previously, the fuel received only 450 days of equivalent full-power irradiation.

Fig. C-1. Estimated Storage Temperatures of Peach Bottom I Core 1 Fuel.