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Retrieval effects on ventilation and cooling requirements for a nuclear waste repository

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ABSTRACT; The Nuclear Waste Policy Act of 1982 (Public Law 97-425) and the regulations promulgated in Title 10, Part 60 of the Code of Federal Regulations (10CFR60) by the U.S. Nuclear Regulatory Commission (NRC) for an underground repository for spent fuel and high level nuclear waste (HLW) require that it be possible to retrieve waste, for whatever reason, from such a facility for a period of 50 years from initial storage or until the completion of the performance confirmation period, whichever comes first. This paper considers the effects that the retrievability option mandates on ventilation and cooling systems required for normal repository operations. An example is given for a hypothetical repository in salt.

1 INTRODUCTION

A considerable proportion of the electrical power used in certain parts of the United States is generated in nuclear power plants, in which the heat generated as a result of fission reactions is used to heat water and convert it to steam. This steam is then used to drive the turbines which generate the electricity. Thus, contrary to popular belief, a nuclear power plant is similar to coal- and oil-fired thermal power plants, the only difference being the source of the heat used to convert the water to steam. One major difference, however, is the fact that nuclear plants do not pollute the air as a necessary consequence of their operation. (There will, however, be a local alter[illegible]

In a reactor, the fissionable radionuclides are in the form of individual pellets contained within a zirconium cladding in packages, called fuel assemblies. Eventually, the fuel within a particular fuel assembly will become subcritical ("spent"), and that assembly must be replaced.

In the light water reactors in use in the U.S., fuel assemblies have an average useful life of three years. The spent fuel assemblies are not inert and contain highly-radioactive fission products as well as non-fissionable, but still radioactive, uranium and transuranic elements.

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1 INTRODUCTION

A considerable proportion of the electrical power used in certain parts of the United States is generated in nuclear power plants, in which the heat generated as a result of fission reactions is used to heat water and convert it to steam. This steam is then used to drive the turbines which generate the electricity. Thus, contrary to popular belief, a nuclear power plant is similar to coal- and oil-fired thermal power plants, the only difference being the source of the heat used to convert the water to steam. One major difference, however, is the fact that nuclear plants do not pollute the air as a necessary consequence of their operation. (There will, however, be a local alteration to the thermal regime in rivers used in the cooling process.)

Nuclear fission occurs when certain radioisotopes, namely uranium-235, uranium-233, and plutonium-239, subdivide, as a result of neutron bombardment, into isotopes of smaller elements, themselves radioactive. In the process, neutrons are also liberated that are able to bombard remaining fissionable radionuclides, thus, prolonging the reaction. Fission continues until there are insufficient neutrons to sustain the reaction. The reaction is called subcritical if the rate of neutron production is less than the rate of neutron loss, primarily through absorption in the reactor walls.

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In the light water reactors in use in the U.S., fuel assemblies have an average useful life of three years. The spent fuel assemblies are not inert and contain highly-radioactive fission products as well as non-fissionable, but still radioactive, uranium and transuranic elements.

A legacy of almost 30 years of power generation in nuclear plants — the first commercial plant was opened at Shippingport, PA in 1957 -- there are large quantities of spent fuel assemblies currently stored in water pools at the reactors themselves or at "away-from-reactor" (AFR) storage sites such as the one at Morris, IL. As the limited capacity of such temporary storage facilities is approached, it becomes clear that a more permanent solution is required.

A number of options for permanent disposal of the wastes has been proposed; however, the only option that is feasible using today's technology is isolation underground in mined space within suitable geologic formations. By way of the Nuclear Waste Policy Act of 1982 (NWPA), Congress and the President [illegible] a schedule for construction of two repositories. Three U.S. government agencies have technical responsibilities related to underground repositories for high level nuclear waste, namely:

- U.S. Department of Energy (DOE), which is responsible for site selection and characterization, and repository design, construction, operation, and closure.
- U.S. Nuclear Regulatory Commission (NRC), which is responsible for licensing all nuclear facilities, including geologic repositories.
- U.S. Environmental Protection Agency (EPA) which is responsible for setting acceptable limits for toxic and radioactive substances.

2 THE REGULATORY FRAMEWORK FOR GEOLOGIC REPOSITORIES

The EPA, through its draft regulations embodied in Title 40, Part 191 (40CFR191) of the Code of Federal Regulations (U.S. Environmental Protection Agency, 1984) has set limits for the concentrations of radionuclides and levels of radiation that can be allowed to reach the so-called "accessible environment" -- that is, the environment to which the public has access. To facilitate the licensing process and to ensure that the EPA requirements contained in 40CFR191 are met, the NRC has promulgated licensing and technical requirements for geologic repositories for high-level radioactive wastes in Title 10, Part 60 (10CFR60) of the Code of Federal Regulations (U.S. Nuclear Regulatory Commission, 1984).

3 HOST GEOLOGIC FORMATION

[illegible], however, the "draft" Environmental Assessments (EA's) [U.S. Department of Energy, 1984a; 1984b; 1984c; 1984d; 1984e; 1984f; 1984g; 1984h; 1984i] have identified one site in each of basalt, tuff, and bedded salt as worthy of further site characterization activities. Two other sites, one each in bedded and domal salt, are potential back-ups should any one of the three recommended sites be found to be unacceptable prior to the issue of the final EA's (expected in late 1985).

The "recommended" sites are as follows:

- the Cohassett basalt flow in the Pasco Basin, at the Hanford Reservation in Washington.
- A welded-tuff horizon within the Topopah Springs tuff at the Nevada Test Site.
- A salt bed in the Palo Duro Basin, Deaf Smith County, Texas.

The alternate sites mentioned above are:

- A salt bed in the Paradox Basin, Davis Canyon, Utah.
- Richton salt dome, Perry County, Mississippi.

It is necessary to mention that a test facility for defense waste is currently under construction: the Waste Isolation Pilot Plant (WIPP), near Carlsbad, New Mexico. This facility is located at a depth of 2,150 ft in Permian-age, bedded salts. Starting in 1987 (according to the present schedules), high-level wastes will be emplaced in this facility for a period

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It is not the intent of the NRC, apparently, that retrievability directly influence the repository design; however, at the same time, it must be shown to be practicable within a given repository design.

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4 REPOSITORY CONCEPTUAL DESIGN

Two phases have been identified for a repository: pre-closure and post-closure. During the pre-closure phase, which comprises the construction, emplacement, and retrievability stages, a repository has three components, namely:

- the surface facilities including waste handling and other service facilities;
- the underground storage rooms, accesses and ventilation drifts; and
- the shafts and/or ramps connecting the surface and underground facilities.

From this point onward, however, the discussion shall be confined to the underground facilities, and, more specifically, the storage areas. The layout and sizing of the storage rooms is dependent on several considerations, namely:

- the storage position -- whether horizontally in the walls of rooms or vertically in the floor of the room. (A third option is so-called in-room, or in-vault, storage, which may come under consideration in U.S. designs);
- the areal thermal load, which depends on the heat generated by a waste container, the spacing ("pitch") of the waste containers within a storage room, and the spacing of the storage rooms; and
- the dimensions of the transporter used to bring the waste containers (contained within transfer casks) from the waste handling shaft to the storage rooms.

With few exceptions, notably the "preconceptual" design for the Hanford site (Rockwell Hanford Operations, 1980), early repository designs assumed that single waste containers would be placed in vertical holes in the floor of the storage assumption that by the time a repository were to be built the number of nuclear power plants, and hence the volume of waste to be disposed, would increase drastically. Due, however, to the recession, conservation efforts, and the aftermath of Three Mile Island, nuclear power plants have not come onstream at the rate that was earlier predicted. This situation does not alter the need for a repository, but rather reduces the required storage capacity. As a result current repository designs have thermal loadings of about 60 kW/acre.

5 RETRIEVAL OF WASTE CONTAINERS

There are two basic scenarios for container ("canister") retrieval — full retrieval, whereby all the containers are removed from the repository, and partial or local, retrieval, whereby container are retrieved only in a section of the repository, whether on a single-container single-room, single-panel, or several-panel basis. Depending on the nature of the host rock as well as the repository design, the rooms in which retrieval becomes required could exhibit three possible situations:

- open and ventilated;
- bulkheaded but unbackfilled, and ventilated by leakage into and out of the panel;
- bulkheaded and backfilled.

In the first case, the ventilation air will remove the heat conducted from the canisters through the rock to the perimeter of the storage room. Hence there will be no special ventilation requirements for retrieval. (This assume layout and sizing of the storage rooms is dependent on several considerations, namely:

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With few exceptions, notably the "preconceptual" design for the Hanford site (Rockwell Hanford Operations, 1980), early repository designs assumed that single waste containers would be placed in vertical holes in the floor of the storage rooms. Later designs opted for storage of multiple containers in long horizontal holes between storage rooms (U.S. Department of Energy, 1982); however, this option has been generally (but not universally) discarded, due, one suspects, at least in part, to the extreme difficulty of retrieving containers from the end or middle of these long holes. (Furthermore, the practicability of excavating 30-in. diameter or larger holes horizontally over lengths in excess of 20 ft remains unproven.)

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In the second case, retrieval wil require breaching of the bulkhead followed by precooling, before retrieva operations can be initiated. The coolin time required depends on the temperatur of the rock, and the rate of airflow. (I the case of salt, slashing may b necessary due to the reduction in openin dimensions as a result of creep closure.)

In the backfilled case, it will b necessary to require a pilot heading unde adverse conditions — high temperature –

in order to establish flow-through ventilation for precooling. Alternatively, pipes may have been laid in the backfill to allow precooling by some fluid medium prior to remining. This, however, would provide considerable complication to the remining scheme. In any case, the backfilled scenario is the most problematic. That does not mean that retrieval under such conditions would be impossible, only rather difficult and requiring a well-conceived plan.

Furthermore, since 10CFR60.111(b) requires that the retrievability option be available from the beginning of the emplacement period, retrieval may be required while storage operations remain in progress. If full retrieval is required, storage operations must necessarily cease. In the case of local retrieval, however, it would be desirable that the retrieval operation not interfere with storage operations, and hence any air volumes required for the retrieval operation must be supplied IN ADDITION to those required for storage operations.

6 EXAMPLE OF A RETRIEVAL SCENARIO IN SALT

We shall now provide an example of the ventilation requirements for retrieval in a salt repository. (It should be noted that this example is not necessarily reflective of current designs which are continually evolving.) It is assumed that mining development operations have ceased so that it is no longer necessary to have the two separate ventilation systems required by 10CFR60. Furthermore, it is assumed that the rooms from which waste is to be retrieved have been backfilled.

Therefore, retrieval will require

enlarged opening may be overly hot, additional precooling may be required prior to retrieval.)

The assumed properties and dimensions are given in Table 1.

Table 1 Dimensions and rock properties of hypothetical storage room.

Room Dimensions	
First Pass	8 ft h x 15 ft w x 540 ft long
Second Pass	20 ft h x 15 ft w x 540 ft long
Average room perimeter wall rock temperature	192°F (assumed)
Desired room perimeter wall rock temperature after cooling	120°F
Intake air temperature	65°F maximum
Salt thermal conductivity, k	2.45 Btu/hr-ft-°F
Salt specific heat, c	0.215 Btu/lb-°F
Salt density, ρ	137 pcf

For the first stage, whereby the pilot is mined by remote control, it will not be possible to provide an environment satisfactory for human presence. One might argue that personnel could be provided with heat-resistant suits whose interiors are air conditioned, i.e. space suits. These suits, however, cannot be assumed to provide radiation protection (Post, 1982); hence, human presence during this remining stage cannot be allowed.

However, once a flow-through ventilation circuit has been re-established and the rock has been sufficiently cooled, human presence can be allowed. For the assumed

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Therefore, retrieval will require remining. This remining can be envisioned to require three steps before retrieval can be accomplished:

- mining of a pilot with a remotely-controlled roadheader or continuous miner, with air provided to the back of the machine via a ventilation duct,
- precooling of the salt in the room by the creation of a ventilation circuit through the pilot heading.
- excavating a bench to bring the remined room to the required height. (Note that as the temperature at the *floor* of the

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However, once a flow-through ventilation circuit has been re-established and the rock has been sufficiently cooled, human presence can be allowed. For the assumed temperatures in Table 1, a maximum temperature at the exhaust end of the room of 104°F and for a 3-month precooling period, the required air flow in a room with a cross section of 8 ft by 15 ft (first pass) is about 13,500 cfm. This air flow is determined using the tables developed by Starfield (1966) and the method described in Hartman et al. (1982). (To perform this cooling, 47 tons of refrigeration would be required.) If retrieval is to be completed in a panel within one year -- a time period equivalent to the storage rate -- precooling or retrieval operations must occur in approximately 1/3 of the rooms in the panel at any given time. Thus, if a panel contains 74 rooms, 25 must be ventilated at any given time. Therefore, the required total air flow would be 337,500 cfm for full retrieval. The air flow for local retrieval depends on the number of affected rooms and therefore would be a multiple of the 13,500 cfm determined above. (Note that these air flows are small by mining standards.)

As discussed previously, local retrieval could be required while storage operations remained in progress. These operations which comprise storage hole drilling, waste emplacement, and backfilling would be carried on in several rooms all of which would require ventilating air. The air requirements in these rooms would depend on diesel and electric horsepower requirements, based on 100 cfm/HP and 20 cfm/HP, respectively. (At the depths currently assumed for repositories in the Palo Duro and Paradox Basins, the virgin rock temperature is low enough (about 88°F) that precooling or refrigeration is unnecessary from a temperature standpoint. In locales having significant humidity, conditioning or stilling chambers are required on the intake size of the ventilation system even for temperatures in the range of 70 to 80°F (Jacoby, 1985). Assuming a 250-HP diesel transporter, a 78-HP diesel storage-hole drill, and 800-HP electric pneumatic backfilling equipment, the total operations air flow for each room requirement is dictated by the flow required by the transporter. (Requirements are not cumulative.) The number of rooms to be ventilated would then dictate the total flow for storage requirements. Presuming that four rooms must be ventilated at a time as a minimum, the required air flow for storage is 100,000 cfm. Therefore, if storage and local retrieval occur concurrently, the 13,500 [illegible] retrieval must be

CONCLUSION

The air flow requirement for retrieval (if necessary) will depend on whether local or total retrieval is required. In the case of local retrieval, the additional air flow may impact operations if development operations are still in progress. Otherwise, the combined development and containment ventilation systems should, in most cases, have sufficient total flow to allow local retrieval. In the case of full retrieval, other operations necessarily cease - and therefore the available air flows should be sufficient. However, from a licensing standpoint, it is necessary to move the sufficiency. Retrieval operations and its ventilation requirements must therefore be basic parts of any repository operations analysis.

ACKNOWLEDGMENTS

The author would like to thank Wyman Harrison, Associate Director for Geoscience and Engineering, Energy and Environmental Systems Division of Argonne National Laboratory for encouraging the preparation of this paper, and Ms. Mary Tisue of the EES Division for editing the manuscript. He would also like to thank Francis S. Kendorski of Terraform Engineers, Inc. for reviewing the manuscript and offering comments and suggestions.

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The governing air flow is, therefore, the 337,500 cfm required for full retrieval. This, however, assumes a literal interpretation of the retrieval time requirement and slightly longer times could be allowed. Thus, the number of rooms to be treated at a time could be halved without a large adverse effect. This then reduces the air flow requirement to 169,000 cfm, which could likely be provided by combining the capacities of the development and emplacement ventilation systems.

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DISCLAIMER