DESTRUCTIVE CONSOLIDATION SYSTEM

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ABSTRACT

This paper describes a simple volume reduction method for all types of PWR and BWR spent fuel. The system was designed to mitigate three major concerns associated with the waste management system currently envisioned by the Office of Civilian Radioactive Waste Management. The first concern is the complexity of the consolidation equipment. The second concern is maintaining the cladding at approximately 375° after it is placed at the respository, and the last concern is the overall system cost to dispose of this waste.

The design approach used for the Destructive Consolidation System (DCS) was to minimize the number of moving parts, to employ simple, rugged mechanisms for all operations and to consolidate spent fuel quickly. It is estimated that this system will only require major maintenance annually or semi-annually. The consolidation rate is expected to be one PWR fuel assembly every 15 minutes and two BWR fuel assemblies every 20 minutes. At this rate only one hot cell will be required to process 4,000 MTU of spent fuel per year if the cell is operated 80 hours per week. This includes a 26 hour per week allowance for minor maintenance, decontamination and contingency time.

In constrast, the current Monitored Retrievable Storage Facility design requires four consolidation hot cells either operating or being maintained continuously throughout the year.

The process is called destructive consolidation because the fuel pin cladding is ruptured during the compression/consolidation cycle. It may appear that spent fuel would be "safer" if the cladding were left intact but just the opposite may be true. Each fuel pin is pressurized with an inert gas when it is manufactured. During burnup, additional radioactive gasses are generated. If fuel is disposed of in this condition each fuel pin represents a pressurized container which could supply the motive force to disperse radioactive particles should a breach occur. The environmental protection provided by the .024 inch zirconium cladding can easily be replaced by an incremental increase of the disposal package wall thickness.

If the fuel cladding does not have to remain intact for geological disposal, the second concern, cladding temperature, is eliminated and an important cost benefit is obtained. The current spacing of repository packages was determined by the cladding temperature limit, but with this constraint removed the packages can be closer together. The spacing will then be determined by the temperature limit of the geologic media and this distance is estimated to be approximately one-half of the current spacing. It is anticipated that the reduced mining requirements in a salt and tuff repository will result in a cost savings of $1.3 billion for the Repositories Waste Management Programs.

The repository mining cost reduction, combined with the reduction in MRS facility construction, operating, and maintenance costs will result in an overall savings of $1.675 billion. This represents a 10% reduction to the total system cost estimate of $16 billion.

Another advantage offered by DCS is a significant reduction in personnel exposure due to 1) reduced consolidation operation time, 2) reduced number of personnel required for consolidation, 3) reduced maintenance time and 4) less spent fuel packages to transport. These factors combine to produce an overall exposure reduction of 8% to 10%.

INTRODUCTION

The direction provided by Congress in 1982 through the Waste Policy Act calls for the Department of Energy to begin taking possession of spent nuclear fuel in 1998. To meet this objective the DOE has established repository project offices to investigate the methodology for disposal in various geologic media and to begin the siting, licensing and design activities required to meet the Department's objectives. These activities have been in progress for several years and during this time, due to the different geologic media and associated design requirements, each office has developed its own unique waste package design and approaches to the handling, packaging and disposal of spent fuel.

Perhaps this design diversity prompted the DOE to begin a re-evaluation of the entire program in an attempt to make the system pieces fit and function better as an integrated system. In any case, the DOE is now apparently convinced that an Integrated Monitored Retrievable Storage Facility (MRS) will be a cost effective step toward spent fuel disposal in deep geologic repositories.

It took a great deal of determination and a certain amount of risk for the DOE to make the MRS decision. Critics of nuclear power, naturally, were not happy with the decision but from an engineering and economic perspective, building the MRS is the correct and commendable thing to do. There are going to be other unpopular decisions that must be made and this paper is an attempt to describe one that has been made but should, perhaps, be reevaluated.

Background

A spent fuel canister has been incorporated into the current MRS design. This canister is used to encapsulate the fuel before it is placed into the repository disposal package. The canister has some interesting design criteria that must be addressed to achieve integration with the rest of the system.

- Its length must accommodate the longest and the shortest intact fuel elements expected to be received at the MRS.

- The canister diameter must be sized to hold a whole, multiple number of consolidated fuel elements and should achieve its highest volumetric efficiency when encapsulating consolidated fuel.

- The canister must handle the pressure generated when all of the fuel pins rupture at the design temperature limit.

- The canister used must not impede the heat transfer from the fuel to the geologic media.

- The canister must be adaptable to the repository overpack.

•Serious consideration must be given to this criteria because several thousand of these canisters must be fabricated for spent fuel disposal. The canister designer needs to also consider the following operational and manufacturing criteria. The canisters should:

- Use standard industrial components (e.g., ASTM standard pipe diameter).

- Be simple to assemble.

- Lend themselves to having the final seal well performed remotely.

- Be easily decontaminated.

- Be amenable to leak verification testing.

- Be volumetrically efficient (square shapes are not as efficient as cylinders and partically empty canisters are certainly not efficient).

- Not require internal support or heat transfer structures.

Meeting these two sets of criteria will be difficult, if not impossible, and to make things even more complicated, there are additional considerations that must be factored into the canister design. Several utilities are planning to increase their spent fuel storage capacity by consolidating their fuel into containers which can then be stored in their existing fuel racks. Currently, no standard has been established for the design of these containers and consequently the MRS designers must prepare to handle fuel consolidated at the reactors.

The current MRS design includes four large hot cells and two hugh hot cells devoted to receiving, storing, consolidating and packaging all types of incoming fuel. Each cell will require four operating crews to provide year round coverage. These cells will be handling contaminated material and periodic decontamination of the cells and equipment removed from the cells for maintenance will be necessary. The decontamination activities will require a large crew to perform the activities and manage the waste streams that they will generate.

The plan for the two huge hot cells in the MRS facility is to prepare repository ready packages for any type of repository. This is a key element of the integrated MRS and it appears to make economic sense to collect as many functions as possible and the largest and most complex facility.

This is especially true from the secondary waste stream generation standpoint. One place to handle decontamination solutions is certainly less expensive than one at each repository and the MRS. But, before all of these functions are located at the MRS, there are some other aspects of the situation that must be considered because they affect the above ground facilities at the repositories.

The repositories will definitely have to have a hot cell to unload transportation casks and handle packages ready for placement into the geology. This hot cell will need as a minimum:

- a remotely operated crane.

- an electromechanical manipulator.

- an inspection station to verify that packages are not damaged.

- a large storage area.

- remotely operated grapples.

- receiving and discharge ports for casks and transporters.

The important fact is that this cell will be fairly well equipped to handle rather complex remote operations, and a modest increase of waste package handling and welding equipment will not create a significant cost impact to the facility.

A reasonable alternative to bringing everything to the MRS is to leave the preparation of waste package at the repository instead of placing the function at the integrated MRS. The reasoning for this conclusion is:

- There must be a hot cell at the repositories regardless of the functions performed at the MRS (waste package must be removed from the shipping cask).

- Shipping a waste package will be more expensive because of the extra tons of steel or iron that will be shipped as a radioactive mass.

- Depending on manufacturing locations, waste packages may have to transverse the country two times (once empty, once full).

- Two different cask designs will be necessary because of the different waste package sizes.

- Cask lid handling equipment at the MRS and at the repositories will have to be designed for two different package sizes.

- The exit ports at the MRS will have to be designed to handle two different casks.

- The receiving ports at the repositories cannot share the same design (different casks).

If the repository hot cells were designated as the location to overpack the spent fuel canisters with the waste package, the following benefits could be realized.

- One cask design could be used for both repositories to ship the fuel from the MRS.
- Canisters can be inspected easily (waste package overpacking if performed at the MRS, would make inspection of canisters almost impossible).
- Shipping costs would be reduced (less material to transport).
- The hot cell at the repository could be used for overpack welding operations.
- The very complex repository preparation cell at the MRS becomes less complex and a single component failure would have a lower probability of affecting operations.
- Secondary waste streams at the repositories should not increase because the hot cells will be handling clean spent fuel canisters.

All of these diverse considerations can be meshed into an integrated system by the development of a standard spent fuel canister. However, before a standard canister can become a practical and effecient part of the system, the fundamental road block of intact cladding must be removed.

Complex engineering analysis and studies have shown that the clad must stay at approximately 380^{o} centigrade to prevent long term creep of the clad and subsequent failure. This is the major factor that determines the spacing of packages in the repository and subsequently the costs of disposal are affected dramatically by how much media must be removed to place a single package. If the cladding temperature was eliminated as a design criteria, the waste package could be spaced on a single, rather simple factor: the thermodynamic performance of the geologic media. Preliminary studies to determine the spacing based on geologic thermodynamic performance indicate that spacing the packages at one-half of the current distance is a reasonable assumption for estimating purposes. If this proves to be acceptable, then the waste package mining costs for each repository could be reduced by approximately 50%.

An economic analysis of the entire spent fuel cycle was recently performed under a contract for the DOE. The program used to perform this analysis was also used to evaluate the cost savings for two repositories if the current waste package spacings were reduced to one-half. For a salt repository the savings are estimated to be approximately 233 million dollars. The corresponding savings in a Tuff repository, because of the higher mining costs, will be approximately $1.04 billion. These savings are based on an overall system cost of $16 billion. The benefit of a standard canister without a cladding temperature limit is clear. One last question remains to be answered; how can the many different sizes and shapes of fuel be packaged efficiently into a standard canister?

When the intact fuel cladding restriction is eliminated, repackaging can become a rather straigt forward operation and many different methods could be used. For instance, the fuel could be shreaded, chopped or shreaded into a package of almost any size or shape. There is existing systems and designs for accomplishing this. These approaches are practical but they do create some secondary problems that must be dealt with. When the cladding is ruptured the radioactive and inert gases trapped in the fuel are released - they must be captured for disposal. A second problem is the spent fuel dust generated when the pellets are crushed and sheared. Neither of these problems are simple to address when mechanical destruction is performed in a hot cell.

A technique for repackaging which avoids mechanical destruction is to use a chemical decladding and dissolution system. This methodology is effective and proven, but after the fuel has been solidified into a glass matrix the volume that must be disposed of will increase beyond the original volume. The standard canister shape is easily achieved but the complex processing and volume penalty would probably make the system too expensive for consideration.

A Destructive Consolidation System not only makes the standard canister possible it is simple, employs proven technology and can save an estimated $375 million is MRS capital and operating costs. The cost reduction is possible because only one hot cell is required for consolidation operations (compared to four at the MRS) and only two shifts, working five days per week, are necessary to consolidate the fuel.

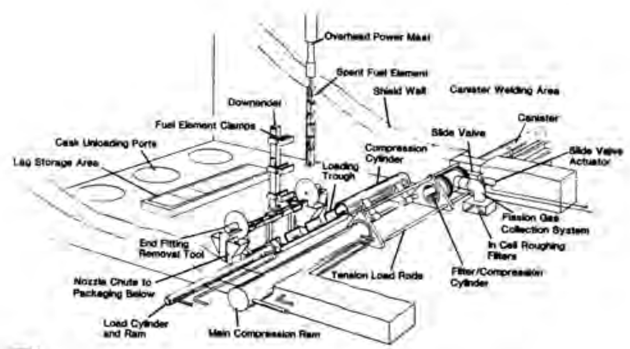

Fig. 1. Destructive Consolidator.

<u>Destructive Consolidation System Equipment</u>

It is assumed that this equipment is housed in an appropriate hot cell equipped with such standard items as electro-mechanical manipulators, overhead cranes, power connections, etc. The cell is also expected to have unloading ports for casks, a lag storage area for spent fuel, maintenance hatches and a discharge for the consolidated fuel.

FUEL ELEMENT DOWNENDERS: This handwave is designed to recieve and grasp two BWR or one PWR fuel element from an overhead crane equipped with a fuel grapple. The DOWNENDER has fuel element clamps mounted along its length and these are activated to clamp the fuel element. The overhead crane fuel grapple is released and the DOWNENDER will then rotate the fuel element to a horizontal position.

LOAD ARM MECHANISM (LAM): As the fuel element arrives in the horizontal position, a second set of fuel element clamps, mounted on the LAM, are engaged and the DOWNENDER clamps are disengaged. The LAM then begins to rotate toward the loading trough. As the fuel element clears the fuel clamps on the downender, it begins to engage the end fitting removal tools. These devices are shown as large abrasive cut off saws but a laser or a plasma torch could be used to cut the end fittings from the body of the fuel element. As the LAM travels past the removal tools. the end fittings are servered and drop into a chute which directs them to a packaging system located below.

The end fitting removal tools are mounted on automatically adjustable bases so they can be positioned quickly to match the length of the fuel element being processed.

The LAM continues its rotation until the fuel element is placed into the loading trough. The fuel element is then released and the LAM is rotated into the start position.

LOADING THROUGH AND LOADING CYLINDER: This mechanism receives the fuel element and positions it for loading. The trough has notches along its length to allow the LAM clearance to place the fuel element on the bottom of the trough. The LAM is then rotated back to its receive position and the LOADING CYLINDER ram is actuated to insert the fuel element into the COMPRESSION CYLINDER. The rams stroke inserts the fuel element into the compression cylinder about one inch before retracting.

COMPRESSION CYLINDER SECTION: This device is designed to pivot into and out of the compression frame to transfer the fuel element from the load position to the compression position. The COMPRESSION CYLINDER also moves a small distance axially, when in the compression position, to engage the seals located on the surface of the FILTER/COMPRESSION CYLINDER.

The entrance end of the COMPRESSION CYLINDER also has a sealing surface designed to mate with the seals on the main compression ram. The COMPRESSION CYLINDER is designed to withstand all stresses imposed during compression of the fuel element and also has its interior surfaces hardened to resist scrapes and abrasion from the fuel element as it is crushed.

After the cylinder is pivoted into the compression position the MAIN HYDRAULIC RAM is activated to begin the destructive consolidation process.

MAIN HYDRAULIC CYLINDER AND RAMS: There are two rams located inside of the main cylinder. The seal compression ram surrounds the main compression ram and its function is to move the Compression Cylinder axially, which in turn, moves the FILTER/COMPRESSION CYLINDER axially to engage seals located between all components. After the seal compression ram completes its stroke, the fuel element is totally sealed inside the compression chamber. At this time the MAIN RAM begins its stroke. The first part of the stroke will move the fuel element into the Filter/ Compression Cylinder and when the end of the fuel element meets the blank section of the Slide Valve it is crushed into a cylinder and should reach 90%+ of its therotical density. The system uses a hydraulic pressure of approximately 10,000 PSI which produces a crushing force of about 1,000 tons.

After the fuel element is consolidated into a solid mass, the hydraulic pressure is reduced to disengage the seals between the Filter/Compression Cylinder and the Slide Valve. The valve is then opened and the hydraulic pressure is re-applied to push the compacted mass through the Slide Valve into a canister which has been positioned and sealed to the discharge port.

The Main Ram is then retracted; the slide valve is closed; the seals are disengaged and the compression cylinder is returned to the load position.

FILTER/COMPRESSION CYLINDER: This cylinder is designed to act as a conduit for gasses that are released when the fuel pins are ruptured. The interior surface is hardened and is perforated by small holes which provide a path for the gasses into the Fission Gas Collection system. The holes are sized to prevent most of the dust particles from escaping. The particles that do pass through the cylinder wall are directed to incell roughing filters.

SLIDE VALVE: This device serves two purposes, the first is to act as a bottom or stop for the main ram as it forces the fuel element into the compression cylinder. The face of the valve seals to the end of the filter/compression cylinder and also seals to the steel shielding wall when the compacted fuel element is being discharged through the side valve into the canister (section function). The valve body is free to move a limited axial distance to compress the seal between the valve and the shield wall.

FISSION GAS COLLECTION SYSTEM: The purpose of this system is to collect the gasses released during the consolidation process. The design of the compression section and its seals will limit the amount of extraneous gasses that enter the system and need to be processed. The first step is to filter the particulate matter that may pass through the filter/compression cylinder. These filters would be removed as required and be disposed of by placing them in with the spent fuel during a compression cycle.

The gasses are then directed to a cyrogenic liquidification system where the radioactive gasses are separated from the inert gasses. Krypton is the only remaining gas (assuming 10 year old fuel) that retains a significant amount of radioactivity and a liquid nitrogen spray tower does an excellent job of capturing krypton. The nitrogen is then selectively distilled to remove the krypton which is then packaged for industrial use, storage or disposal.

This basic cycle is repeated until an appropriate number of fuel elements have been consolidated and injected into the spent fuel canister. If the diameter of the canister is set at 14 inches (nominal), it will hold (depending on the height) four to five PWR elements. In the call of PWR elements this represents a 33% to 66% increase in capacity for a modest increase in diameter. This represents a considerable reduction in handling effort and a corresponding reduction in personnel exposure.

In summary, the spent fuel waste system can be designed for an efficient, logical operation if we are willing to part with some cherished ideas and approach the problems from an integrated systems perspective.

REFERENCE

1. Westinghouse Electric Corporation Waste Technology Services Division; Tennessee Valley Authority and Florida Power and Light Company, "Phase I, Study of Generic Cask Systems for Spent Fuel Management from Reactor to Repository," DOE Contract Number DE-AC01-84RW00003.