WASTE STREAM ANALYSIS MODEL

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ABSTRACT

A description is provided of the Waste Stream Analysis (WSA) Model which is used by the Department of Energy to simulate the life cycle history of waste stream flows and characteristics within the federal waste management system. The model tracks the location and characteristics of fuel assemblies and matches cask, waste package, and emplacement loadings to the physical and radiological characteristics of spent fuel at the time of handling. The capability of the model for providing data and insights into the control of waste characteristics via selection is illustrated by use of two bounding, and one intermediate waste selection method. It is concluded that prudent fuel selection can result in significant and beneficial control of both the time behavior and variability of waste characteristics.

INTRODUCTION

The Office of Civilian Radioactive Waste Management (OCRWM) has the responsibility for managing the ultimate disposal of the nation's spent nuclear fuel and high level radioactive waste. To execute this national priority, OCRWM needs accurate information about the quantity and characteristics of the nuclear waste it expects to receive. The Waste Stream Analysis (WSA) model (1) was developed to address this concern. WSA has two major applications: (i) to support OCRWM program offices and facility and package designers by developing information about the characteristics of the waste stream under alternative operating assumptions; and (ii) to support the Office of Systems Integration as part of an integrated modeling system.

The purpose of this paper is (i) to present an overview of the Waste Stream Analysis Model, (ii) to illustrate the wide range of spent fuel characteristics that can be provided by the Waste Stream Analysis Program, and provide examples of specific data on spent fuel characteristics at the time of handling, and (iii) to demonstrate how the use of waste selection and sequencing methods can impact waste characteristics. The results presented in this paper were extracted from The Use of Spent Fuel Selection Strategies to Control Waste Streams (2), which is a detailed compendium describing the impacts of spent fuel characteristics on the Federal Waste Management System (FWMS). The results presented in this paper utilize and are complementary to the Oak Ridge National Laboratories (ORNL) Characteristics Data Base (CDB) (3).

The overall DOE acceptance and processing schedule is taken from Table 2-2 of the Draft 1988 Mission Plan Amendment (4). (In this study, the MRS is assumed to operate on a flow-through or last- in, first-out basis.) The allocation of acceptance rights among individual reactors is consistent with the Standard Contract (5) between DOE and the utilities, which is based on the final discharge dates, i.e., an oldest-fuel-first queue. It is emphasized, for the purposes of this study, that the fuel actually selected for delivery within an allocation does not necessarily have to be the same fuel (i.e., oldest) on which the allocation was based.

First, this paper presents an overview of the WSA model. Next, a number of results produced by the WSA program are provided, along with an analysis and discussion of their relevance to the FWMS. The paper then summarizes the ranges of certain characteristics at the time of handling by using three waste selection sequences -- the oldest fuel first (OFF) sequence, the youngest fuel first (YFF5) sequence (selects the youngest available fuel that is at least 5-years cooled), and the youngest fuel greater than 14 years sequence (YFF14). Finally, the paper summarizes characteristics that are of particular interest in Systems Analysis, including a comparison of OFF, YFF5 and YFF14 sequencing and the impact of various priorities on acceptance of fuel from decommissioned reactors. The latter is a hypothetical situation in which acceptance priority is given to fuel from decommissioned reactors (DECOM), with OFF sequencing applying within the revised allocation. For this case, reactors are granted decommissioned priority pickups five years after they retire from service, and at that time all their remaining spent fuel is removed.

WSA MODEL

Overview

The Waste Stream Analysis Model provides the capability to characterize the nuclear waste stream and evaluate impacts of a wide range of operating conditions on the Federal Waste Management System (FWMS). WSA simulates the movement of nuclear waste through the major elements of the FWMS and tracks the history of each assembly from the time it is discharged from the reactor to the time it is ultimately emplaced in a geologic repository. WSA can select from a list of available shipping casks and waste packages the ones that will match the radiological and physical characteristics of the spent fuel, and track the movement of the selected shipping casks and packages. The model can characterize spent fuel inventories, movements and containerization in terms of fuel type, burnup, age, heat, individual isotopes, gammas, and neutrons.

WSA has a broad scenario specification for selecting and sequencing fuel to be picked up from the reactors. Fuel selection can be based on age (oldest, youngest), heat, form (consolidated, intact), location (in pool, in dry storage), etc., while respecting reactor acceptance rights. The user can specify transportation mode between facilities and also specify whether unit trains are utilized. Priority can be granted for emergencies or decommissioning. Fuel handling processes at the repository and MRS, if included in the system, are also simulated. Fuel may be packaged intact and/or consolidated at either the MRS or repository. Fuel packages may be tailored to assembly types and heat ranges. WSA has several options for managing silo storage at the MRS.

The general containerization capability, i.e., the selection of shipping casks and waste packages to match the waste characteristics, is one of the most powerful features of WSA. WSA chooses containers based upon a user-specified priority. WSA puts a group of assemblies in the highest priority container available to that assembly-group type that does not violate heat or dose rate specifications of the container. WSA will derate a user- specified container if none of the available containers can be fully loaded without exceeding container design limits. Waste package heat specifications are evaluated at the time the waste package is emplaced, which may be different than the time it is packaged. WSA can also be used to estimate areal loading requirements.

Data

The two primary data inputs for WSA are the spent fuel discharges from commercial nuclear reactors and the spent fuel physical and radiological characteristics, both from ORNL's CDB. The spent fuel discharge schedules are obtained from the portion of the CDB developed by the Energy Information Administration (EIA). Historical discharges are collected from the utilities on Form RW- 859; projected discharges are obtained from EIA's desegregate forecasts. The physical and radiological characteristics of the spent fuel in the CDB were developed by Oak Ridge National Laboratory.

Reports

The WSA model develops a detailed Spent Fuel Activities data base that tracks the containerization and movement of the spent fuel through the FWMS. The WSA reporting system is a large collection of standardized reports that summarize this data base and calculate time and location dependent characteristics of the spent fuel. Reports are produced at various levels of detail in both tabular and graphic form. Some report programs summarize data derived from a single set of operating conditions and assumptions, while other reports compare statistics from scenarios based on different operating conditions and assumptions.

WSA reports can generally be grouped into two categories: summation reports and statistical distribution reports. Examples of summation reports are the annual amounts of BWR or PWR spent fuel received by the MRS, the annual number of loadings for each shipping cask type, etc. Distributional reports include burnup, age, assembly length, heat, and integral heat. Other distributional reports cover neutrons, photons for 18 gamma energy ranges, and curies for over 350 isotopes. Distributional reports can be referenced to the spent fuel assemblies processed during a specific year (e.g., heat distribution of the fuel accepted into the FWMS) or to spent fuel containers (e.g.,heat distribution of waste packages emplaced each year).

WSA also contains a series of specialized report programs that summarize assembly data reported by the utilities on Form RW-859. These reports provide accurate characterizations of the assemblies discharged to date. Examples are reports that analyze the burnup-to-enrichment relationships of the spent fuel to identify specific assemblies that are candidates for burnup credit.

RESULTS

The purpose of this section is to illustrate the magnitude, range, and sequence of various characteristics of spent fuel at the time of handling in the Federal Waste Management System. These data add the "time-of-handling" dimension to the spent fuel discharge data. Waste characteristics at the time of handling are needed for the design of transportation, MRS and repository facilities and equipment, and for systems analyses leading to improved waste selection, sequencing and operations. Importantly, this work also shows that spent fuel characteristics can be controlled and managed within definable ranges by controlling the time of handling.

The waste characteristics of primary interest fall broadly into (i) radiation (including thermal) and (ii) physical (including dimensional) categories. The designers of fixed facilities make prudent choices of upper-limit radiation and dimensional characteristics and the magnitude and variability of characteristics is of only minor subsequent interest. In contrast, the designers of the various waste containers (casks and waste packages) and emplacement have significant impact and cost minimization incentives to match containers and emplacement as closely as possible to waste characteristics. In particular, the magnitude, variability and time dependence of waste radiation and thermal outputs is of primary interest, and the spectrum of dimensions, particularly fuel assembly lengths, are needed for selecting appropriate internal dimensions for casks and waste packages. Because spent fuel radiation and thermal outputs are determined largely by discharge burnup and fuel age, burnup and age histories of fuel provide designers with the primary data needed for design.

From Reactor Shipment and Receipt at MRS

The radiological characteristics of spent fuel depend upon the fuel burnup and its age at the time of handling. Of the important radiological characteristics relevant to fuel transport, heat output is both relevant in its own right, and is a reasonable surrogate for relative dose external to a cask for spent fuel over ten years old. The age, burnup and heat impacts of two limiting and one intermediate waste selection method have been evaluated. The annual average age, burnup and heat outputs resulting from the three selection methods are compared in Fig. 1. The most relevant comparison is that of heat output. This clearly shows that the YFF14 selection method results in more moderate and constant time behavior, with smaller extremes than either the OFF or YFF5 methods. A conclusion based on this observation is provided below.

It is likely that different cask designs will be required for each of the four combinations of BWR/PWR fuel types and truck/rail-capable reactor sites. The annual quantities to be shipped by each of the four cask types, assuming strict allocation-based cask scheduling have been evaluated and are shown in Fig. 2. The significant annual variations of up to 20 or 30 percent of average values are noteworthy and are the subject of a conclusion, below. In addition, the spectrum of lengths of fuel assemblies has been developed, as shown in Fig. 3. This clearly shows that a significant amount of (PWR) fuel can be accommodated by a cask with a minimum internal cavity length of about 160" and that additional large increments (mostly BWR) can be handled by casks with internal lengths between 172" and 176". It is noted that the typical shorter length of PWR fuel and its need for greater shielding (higher burnup) relative, to BWR fuel, are two differences that can be resolved by having different BWR and PWR cask designs.

The neutron output of spent fuel, when coupled with the effective multiplication factor of the spent fuel, provides the neutron source term for cask neutron shielding design. The annual average neutron output of spent BWR and PWR fuel is shown in Fig. 4. These figures show the differences between the selection methods that were noted, for example, in the comparisons of heat outputs: the low-to-high extremes of OFF, the high-to-low extremes of YFF5 and the more moderate and stable behavior of YFF14. It should also be noted that the neutron output of PWR fuel is approximately double that of BWR fuel, even though PWR burnups exceed BWR burnups by only about 25%, on average. This serves to emphasize the extreme sensitivity of the neutron source term to burnup.

The Co60 isotope is among the most important of many activation and fission products which, in total, yield the source term for cask gamma shielding design. Although the Co60 data are not, by themselves, needed for cask design, the data for this individual isotope are indicative of the level of detail that can be provided by the WSA Program. The annual average activity of Co60 in PWR fuel at the time of transport and receipt into the DOE system is also shown in Fig. 4. Co60 content and location within a fuel assembly is of concern to cask designers because of its high- intensity gamma radiation and its possible location in end fittings in the cask top and bottom areas where shielding may be less. Co60 is an activation product of the cobalt in steels used in springs, grid structures and end fittings. Because of this, the amounts of Co60 depend on specific fuel designs and the data presented here, being averaged, is not necessarily representative of a particular design. However, a number of features of the average data should be noted. Being an activation product, the Co60 activity at discharge is

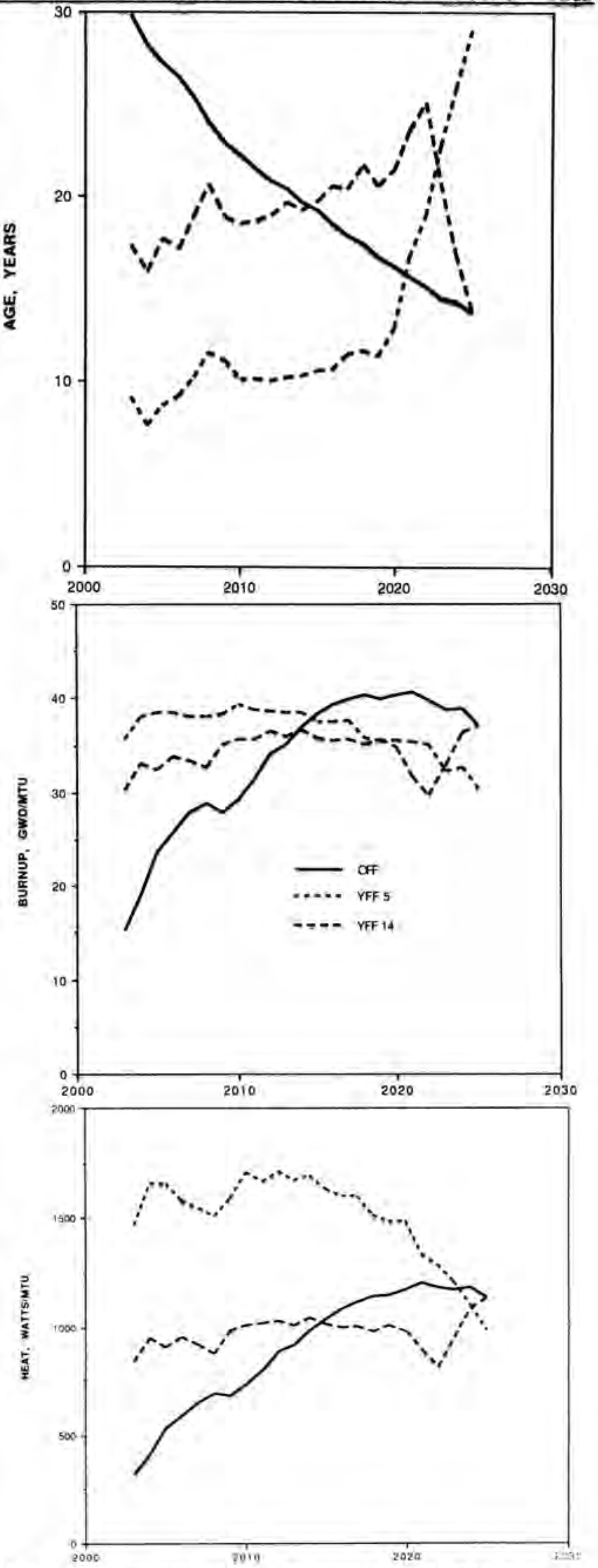

Fig. 1. Comparison of Age, Burnup, and Heat at Time of Emplacement.

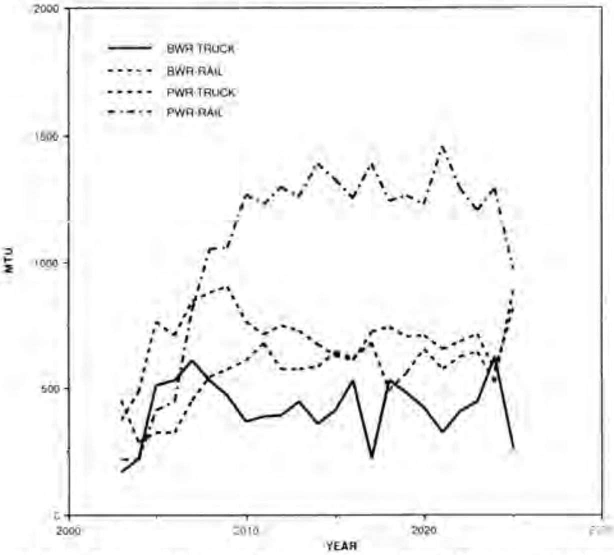

Fig. 2. Annual Quantities of Spent Fuel Received, OFF.

approximately proportional to burnup, but because of its relatively short (5.3 year) half-life, it exhibits significant sensitivity to age at the time of handling.

From-MRS Shipment And Repository Emplacement

Heat output at the time of waste packaging and the integral heat output between emplacement and the time at which a temperature- related emplacement limit occurs are the radiological characteristics of most relevance to repository emplacement. These depend in part, on burnup and age at the time of emplacement. The annual average heat output and integral heats are compared for the three selection methods in Fig. 5. These show that the YFF14 selection method results in more moderate and stable behavior of the waste characteristics that are important to repository emplacement. It is further noted that these benefits are achieved with only a 2.5% increase in average heat output and only a 0.8% increase in emplacement area requirements, all relative to OFF scheduling which results in the lowest possible average heat and integrated heat characteristics.

System-Related Characteristics

The overall system impacts of using the three selection methods were reviewed and it was noted that because of the general persistence and consistency of characteristics when using any one selection method throughout the system, the favorable observations pertinent to the YFF14 method as applied to transport, and as applied to emplacement, were also applicable to the overall system.

A second system issue was addressed: The possible system impacts of giving acceptance priority to fuel from decommissioned reactors 5 years after shutdown. The impacts on both characteristics and quantities were evaluated. The top of Fig. 6 provides a comparison of the average annual heat with normal (OFF) allocation and with the DECOM allocation method. This shows both the increased variability and the greater radiological intensities (heat, in this case) encountered with decommissioned reactor priority. Of greater potential significance are the extreme

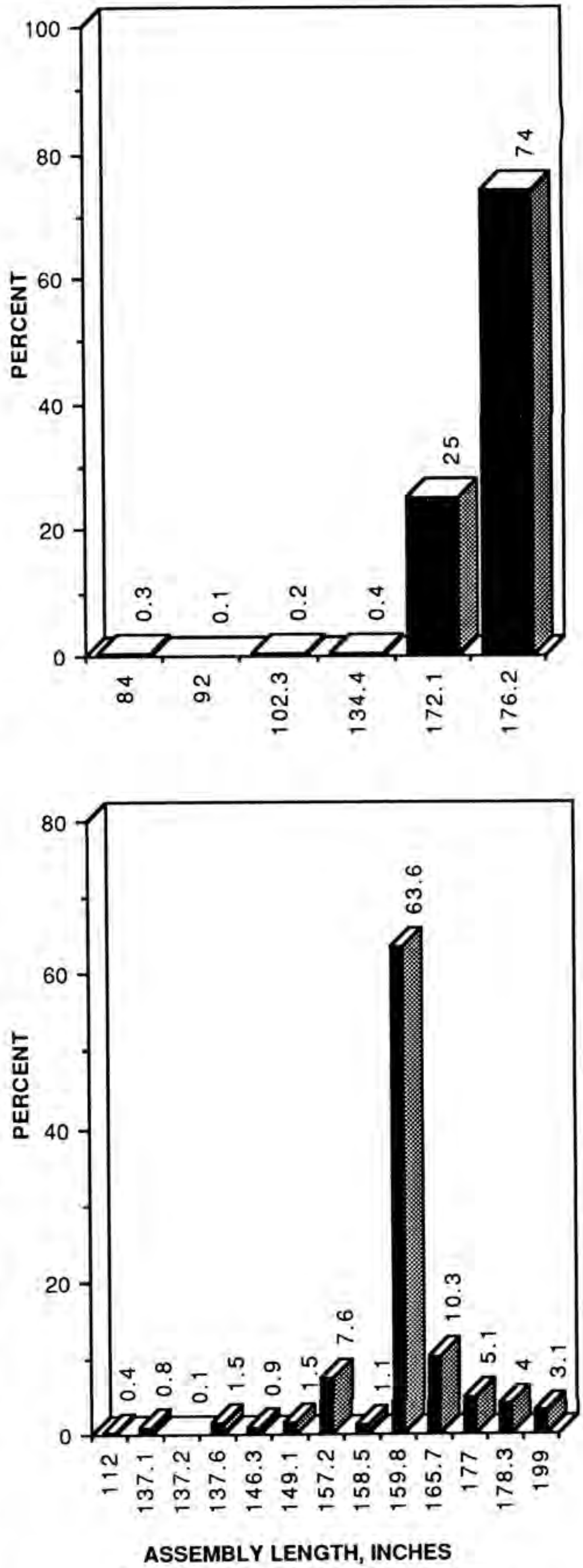

Fig. 3. Assembly Length Distribution.

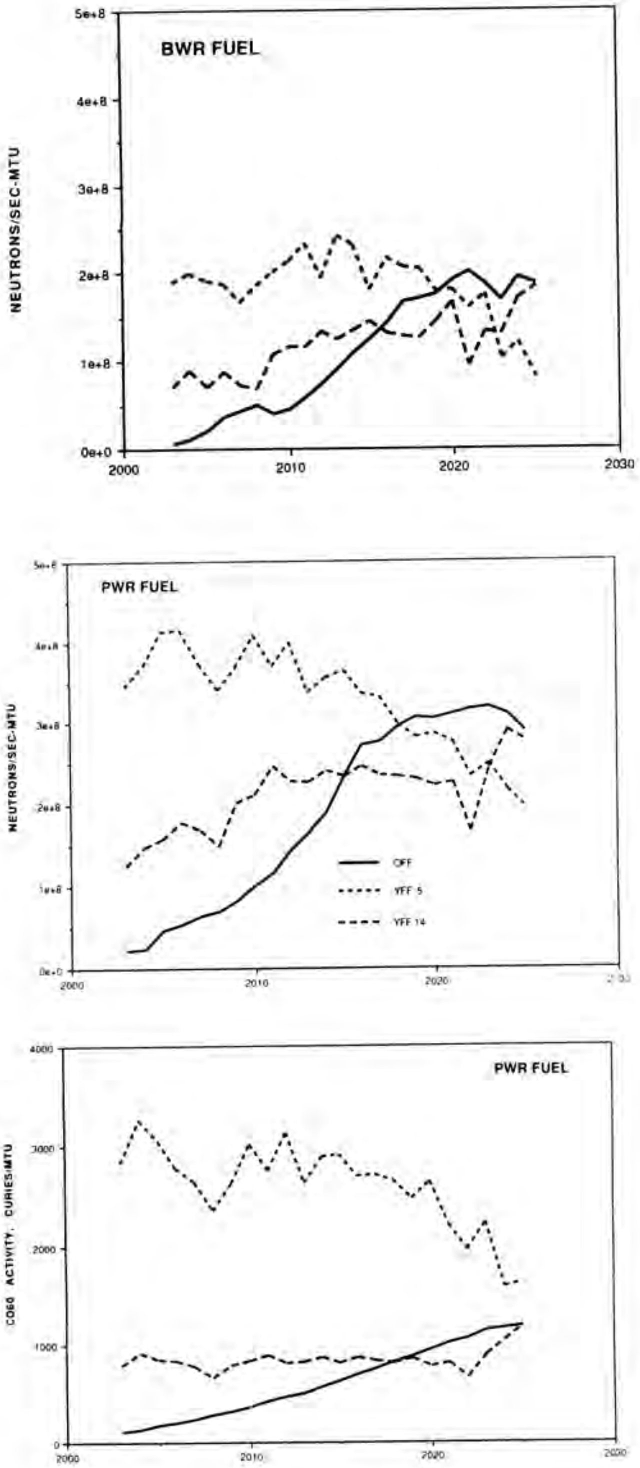

Fig. 4. Average Neutron and Co-60 Activity at Time of Receipt.

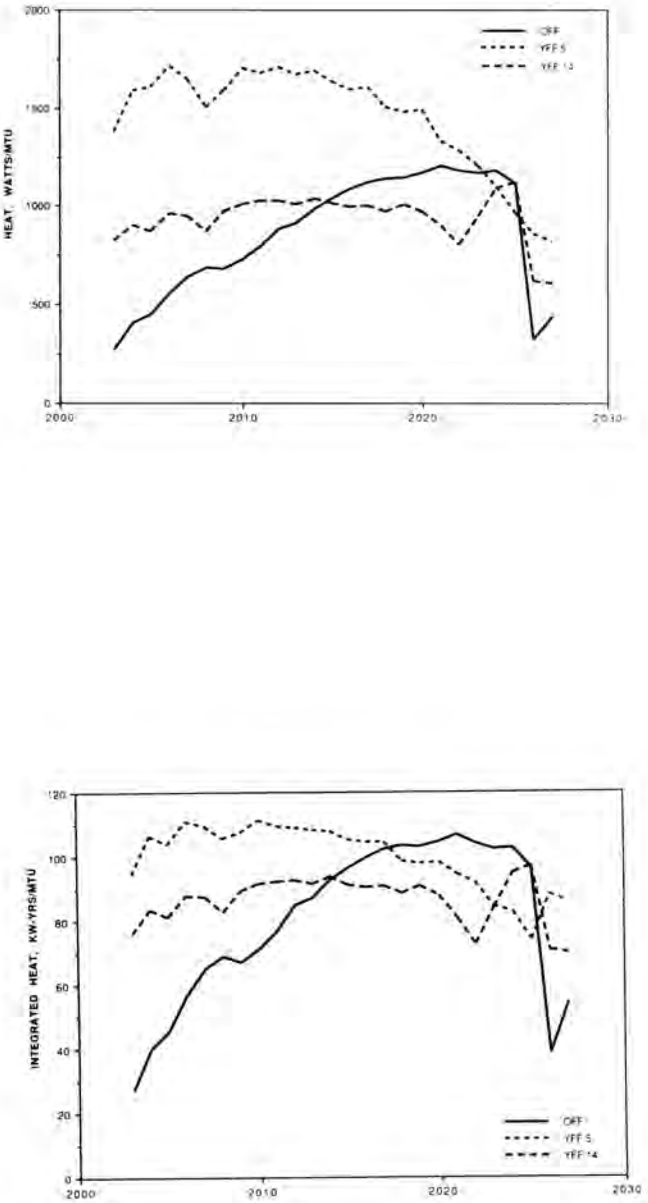

Fig. 5. Comparison of Heat and Integral Heat at Time of Emplacement.

fluctuations of annual quantities to be shipped by a given cask type. The middle of Fig. 6 compares the annual quantities requiring transport in BWR truck casks, which is one of the four general types of casks needed. The extreme fluctuations in quantity requirements are evident. The major impacts on cask fleet requirements and the impacts on waste characteristics and hence on cask design lead to one of the conclusions stated below. Another area affected

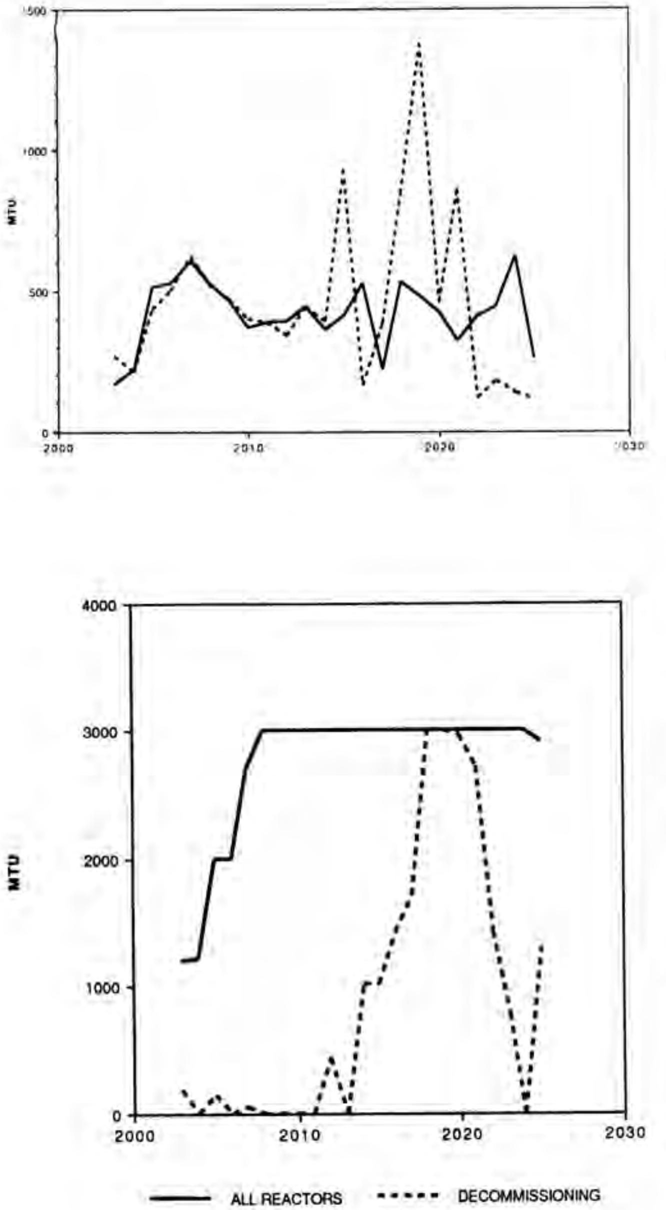

Fig. 6 Impact of Decommissioning Priority.

by granting priority to decommissioned reactors is that of equity, since reactors with oldest first acceptance rights are pushed back in the queue. The bottom part of Fig. 6 highlights the portion of the spent fuel received by the FWMS that is granted priority for decommissioning activities.

CONCLUSIONS

The principal conclusions of this work are:

Benefits of Waste Selection

The use of a simple selection method (YFF14) results in a significant improvement in the constancy and a reduced variability of waste characteristics throughout the DOE system. This method belongs to a general class of selection methods whose basic purpose is to use fuel selection to achieve more uniform and stable waste characteristics. It is concluded that fuel selection can successfully control both the time behavior and variability of waste characteristics within the DOE system. The appropriate level of control and the specific benefits to be realized from such control have to be evaluated for specific system configurations and component designs. The benefits appear to include reduced numbers of transport cask loadings, reduced public impact from reduced transport operations, and reduced costs for the same.

Annual Quantity Variability Among Cask Types

There is a necessary division of cask types between truck and rail-capable sites, and a probable distinction between BWR and PWR-capable casks, resulting in the likelihood of at least 4 different cask designs within the from-reactor transport fleet. Once the system has started up and the total acceptance rate does not vary, there are 20 to 30% annual fluctuations about the average annual quantity to be picked up by each of the 4 different cask types assuming strict overall adherence to OFF- based allocations. This situation has implications for cask fleet sizing, which requires coordination with the utilities. A mutually acceptable tradeoff is required between sizing the cask fleet based on peak requirements, but at higher costs, and sizing the cask fleet based on average requirements and adhering to oldest-first acceptances within each cask category, but with some variance overall.

Impact of Priority Allocation to Decommissioned Reactors

Granting acceptance priority to fuel from decommissioned reactors can have major impacts on the annual quantities of fuel to be shipped by each component of the transport cask fleet and can also impact the specific cask designs within each component. It appears to have less impact on waste packaging and emplacement operations. Its very large impact on casks, cask fleet makeup and utilization leads to the following general conclusion: if acceptance priority is to be given to fuel from decommissioned reactors, that requirement must be addressed in cask design and cask fleet selection, and must also be reflected in the planning for cask fleet operations in order to identify the necessary tradeoff between (i) overall cask fleet makeup, operations and cost, and (ii) the extent of literal adherence of transport scheduling to strict allocation scheduling requirements. If acceptance priority for decommissioned reactor fuel is imposed after the casks and cask fleets are in place, the new requirement will be both more difficult and expensive to implement.

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