HOW MANY GEOLOGIC REPOSITORIES WILL BE NEEDED?

Thomas J. Evans
Geological & Natural History Survey
University of Wisconsin Extension

Robert J. Halstead
Wisconsin Radioactive Waste Review Board
Madison, Wisconsin 53702

ABSTRACT

DOE's postponement of site-specific work on the second repository program has rekindled debate over the number of geologic repositories needed for disposal of high level radioactive waste. The multiple repository approach grew out of the March, 1979 IRG report, which recommended co-disposal of civilian and defense HLW in a system of regional repositories. The multiple repository approach was adopted by DOE, and incorporated in the Nuclear Waste Policy Act passed by Congress in December, 1982. Since the late 1970's, the slower than anticipated growth of the nuclear power industry has substantially reduced earlier estimates of the amount of civilian spent fuel which will require geologic disposal. Reactors currently in operation (78.5 GWe) and reactors in the construction pipeline (28 GWe) are expected to discharge about 103,200 MTU of spent fuel by the year 2036, assuming no increase in fuel burnup rate. By the year 2020, defense high level radioactive wastes equivalent to as much as 27,000 MTU could require geologic disposal. Small amounts of high level waste from other sources will also require geologic disposal. Total disposal requirements appear to be less than 140,000 MTU. The five sites nominated for the first repository, as well as hypothetical sites in granite, the host rock under primary consideration for the second repository, all appear capable of accommodating up to 140,000 MTU.

INTRODUCTION

In January 1987 the United States Department of Energy (DOE) published a Draft Mission Plan Amendment which seeks to clarify the Department's views regarding the number of repositories which will be required, and the schedule for repository site selection.(1) DOE's postponement of site-specific work for the second repository in May, 1986 rekindled the debate over how many geologic repositories will be needed. DOE suggested that there was uncertainty about whether or not the second repository would be needed. The Draft Mission Plan Amendment retreats from that earlier position, and reasserts the need for a second repository based both on the statutory provisions of the Nuclear Waste Policy Act, and on current projections of spent fuel discharges from civilian nuclear power reactors.

This paper presents an overview of the debate over how many geologic repositories will be needed. The evolution of a federal policy based on multiple repositories is traced from 1979 through 1987. The high level waste projections used by DOE are reviewed and evaluated, and alternative projections of civilian spent fuel and defense high level waste are presented. Geotechnical constraints on waste emplacement are reviewed, and the feasibility of accommodating all of the anticipated high level waste in one repository is examined. The paper concludes that one geologic repository can probably accommodate all of the anticipated high level waste, and recommendations are offered for revising national policy based on this technical finding.

EVOLUTION OF THE MULTIPLE REPOSITORY APPROACH

The multiple repository debate has its roots in the report published in March 1979 by the Interagency Review Group (IRG) on Nuclear Waste Management. At the time, federal policy assumed "the selection of a single national waste repository site which would conceivably accommodate all civilian--and defense--generated waste ready for disposal through the end of the century, even assuming an expanded nuclear power industry." The IRG recommended an alternative approach, construction of "several repositories sited on a regional basis insofar as technical considerations permit." The IRG gave four reasons for the recommendation: It would maintain flexibility to accommodate high level wastes from a wide range of nuclear growth and fuel cycle scenarios; it would provide "redundancy that would hedge against the possibility of operational difficulties causing unexpected repository shut-down;" it would reduce systemwide transportation requirements; and it would foster regional equity in the siting of high level radioactive waste facilities. However, the IRG anticipated disadvantages as well as advantages, and warned: "In applying this regional approach, there is a risk that organizational and political commitments might develop to particular regions or locations to such an extent that less than full attention would be given to safety, environmental and security considerations. Therefore, the DOE must be certain that technical adequacy is a prerequisite for site selection and must provide adequate assurance to the public in this regard."(2)

The IRG recommendation was adopted by DOE, and became the basis for DOE's generic environmental impact statement (EIS) published in October 1980. The generic EIS envisioned a system of two or more repositories sited regionally, with capacities of 50,000 to 120,000 metric tons of uranium (MTU) each determined primarily by the thermal loading capacity of the host rocks under consideration (basalt, granite, salt, and shale). Further, the generic EIS presented a forecast of spent fuel disposal requirements depending upon different nuclear power growth assumptions, ranging from 10,000 MTU (all reactors shut down in 1980) to 427,000 MTU (500 GWe system by 2040).(3)

The belief that more than one repository would be needed, encouraged by DOE's forecast of spent fuel disposal requirements, influenced Congressional deliberations between 1977 and 1982, and became institutionalized with passage of the Nuclear Waste Policy Act (NWPA). Congress also sought regional equity, and reduction of transportation impacts, by requiring consideration of regionality in site selection. The Act also reflected the IRG's recommendation for consideration of different host rock types. While establishing schedules for nomination of candidate sites for the first and second repositories, the Act did not specifically authorize construction of a second repository. It did restrict the amount of spent fuel or high level waste which could be emplaced in the first repository to 70,000 metric tons of uranium, "until such time as a second repository is in operation." (Section 114d) Congress also required DOE to issue a Mission Plan spelling out in great detail the Department's plans for implementation of the Act.

DOE issued two drafts of the Mission Plan, both of which maintained that two repositories would be required to accommodate the anticipated volume of spent nuclear fuel. Reviewers sharply criticized DOE's use of overly optimistic projections of civilian nuclear power. In the final version, published in June, 1985, DOE again used highly optimistic nuclear power growth projections to justify the need for two repositories. However, DOE also acknowledged the NWPA requirement for two repositories, and presented a contingency plan under which the first repository could be constructed at a site originally designated for the second repository, if technical or political problems precluded licensing one of the first repository sites. The Mission Plan specified startup dates of 1998 and 2006 for the two repositories, each with a design capacity of 70,000 MTU. DOE acknowledged that 70,000 MTU was "not a minimum or maximum capacity requirement. A suitable site . . . may be able to accommodate less or more than 70,000 MTU."(4)

The Draft Mission Plan Amendment acknowledges the NWPA requirements for a second repository, but stresses the capacity issue again, stating "even the lowest current projections of spent fuel generation . . . indicate that a second repository will be needed." DOE dismisses the contingency plan which had previously been used to justify second repository site work, and drops the Mission Plan's careful explanation that 70,000 MTU is not a technical capacity constraint.(1)

Table I
Summary of Spent Fuel Forecasts by the Energy Information
(thousand metric tons of uranium)

Report Date	By the Year 2000: "No-New-Orders" Case	Low Case	Middle Case	High Case	By the Year 2020: "No-New-Orders" Case	Low Case	Middle Case	High Case
August 1980	(A)	59.6	64.6	69.6	(A)	150.4	167.1	204.0
May 1982	(A)	50.1	54.1	57.4	(A)	160.3	184.1	136.9
February 1983	45.6	45.6	48.2	49.8	84.5	108.3	132.6	156.8
November 1984	46.4	46.8	49.0	50.2	97.7	111.0	130.3	154.5
December 1985	39.9	39.9	41.7	42.2	74.6	87.4	106.4	126.2
September 1986	40.8	40.8 [B]	41.6 [C]	42.0 [D]	79.3	86.8 [B]	106.0 [C]	130.3 [D]

[A] Not included.
[B] Referred to as the "lower reference case" in the 1986 EIA report.
[C] Referred to as the "upper reference case" in the 1986 EIA report.
[D] Referred to as the "optimistic case" in the 1986 EIA report.
(1)

HIGH-LEVEL RADIOACTIVE WASTE PROJECTIONS

Several categories of radioactive waste will require disposal in a geologic repository. The largest is spent nuclear fuel from civilian power reactors. Current planning assumes that civilian spent fuel will not be reprocessed. A small quantity of civilian reprocessing waste will be solidified and sent to a repository.(5) High level radioactive waste from defense activities, primarily nuclear weapons production and naval and military reactors, will also be solidified and sent to a geologic repository. A small amount of miscellaneous wastes, including foreign reactor fuel,(6) will probably require geologic disposal. Transuranic wastes from civilian nuclear power activities will also be disposed of in a geologic repository. Transuranic wastes from defense activities will be buried at the Waste Isolation Pilot Plant near Carlsbad, New Mexico.

Civilian Spent Fuel

DOE uses the annual nuclear power projections by the Energy Information Administration (EIA) as its planning base for civilian spent nuclear fuel. EIA annually publishes Commercial Nuclear Power: Prospects for the United States and the World, and World Nuclear Fuel Cycle Requirements. EIA forecasts Low, Middle, and High nuclear power growth scenarios. In 1983, EIA added a No New Orders case. As of 1986, EIA has renamed the Low, Middle and High growth cases as the Lower Reference case, Upper Reference case and the Optimistic case.(7) As Table I illustrates, the forecasts of cumulative spent fuel discharges for 2000 and 2020 have generally declined year by year in all four cases. The primary reason for the decline has been cancellation of reactor orders by the electric utility industry, and assumptions about extended fuel burnup. The slight increases in the

1986 forecast result from assuming higher average capacity factors for operating reactors, and license extensions to allow 40 years of operation.(8)

There are two problems with DOE's use of the EIA forecasts to determine disposal capacity requirements. First, DOE has elected to use the overly optimistic Middle case or Upper Reference base. Second, EIA does not forecast spent fuel discharges beyond the year 2020.(9, 10) On the other hand, EIA's No New Orders forecast is generally consistent with forecasts by the electric utility industry.(11, 12, 13, 14) The EIA forecast assumptions are explicit, and provide an acceptable basis for estimating spent fuel discharges beyond the year 2020.

EIA's Upper Reference case assumes a doubling of nuclear power capacity over the next four decades. All reactors in the construction pipeline (39 GWe) are constructed or replaced by reactivation of mothballed units. New reactor orders resume in the 1990's and begin operation after 2001. By 2020, installed nuclear capacity reaches 219 GWe. The Upper Reference case makes other optimistic assumptions. All reactors operate for 40 years. The average capacity factor increases from less than 60 percent at present to 65 percent by 2000, and 70 percent by 2020. The fuel burnup rate increases 30 percent between 1983 and 1998 and holds constant thereafter, averaging 31,200 MWD/t for BWRs and 39,900 MWD/t for PWRs.

While EIA's Upper Reference case could represent the future of the nuclear power industry, it is not an appropriate basis for planning the waste disposal system at the present time. There is currently little evidence that the resurgence of the domestic nuclear power industry anticipated in this scenario will occur, and much evidence to the contrary. Even DOE assumes no new orders for civilian reactors until the early-to mid-1990's. The first new reactor orders will have no impact on the waste disposal system until after the year 2001. Finally, planning based on this overly optimistic scenario has major ramifications for other aspects of the nuclear waste program. For example, in determining the appropriate disposal fee for defense wastes, use of the EIA Upper Reference case unfairly shifts costs to utility ratepayers, regardless of which defense waste projection is used.

EIA's No New Orders case is the most appropriate basis for planning the waste disposal system at the present time. Under this scenario, no new nuclear power plants are ordered through the year 2020. Twenty-five reactors (28 GWe) currently in the construction pipeline, are completed in addition to 78.5 GWe of nuclear capacity currently operating. Installed nuclear capacity peaks at 107 GWe in 2007, declines to 55 GWe by 2020, and all units are assumed retired by about 2036. Otherwise the same optimistic assumptions of the Upper Reference case apply: All reactors operate for 40 years, average capacity factor increases to 70 percent by 2020, and fuel burnup rates increase 30 percent between 1983 and 1998.

In Table II, total spent fuel disposal requirements for the No New Orders case are projected using the same assumptions as EIA, except for a slightly higher spent fuel discharge rate. Average lifetime discharges were estimated at 960 MTU/GWe for reactors currently in operation, and 990 MTU/GWe were assumed for reactors in the construction pipeline as of December, 1985. Discharges were calculated for two burnup cases. With no increased fuel burnup, the No New Orders case results in total spent fuel discharges of 103,200 MTU. With increased fuel burnup, the total spent fuel discharges amount to 88,600. The corresponding projections for EIA's Upper Reference case are 214,500 MTU (no increased burnup) and 166,500 MTU (extended burnup).

Table II
Spent Fuel Disposal Requirements,
EIA 1986 No New Orders Case

	Spent Fuel Discharges (metric tons of uranium)	
	Increased Fuel Burn Up - Base Case	No Increased Fuel Burn Up
Current Inventory As of 12/31/85.	12,400	12,400
Currently Operating Reactors (78.5 GWe), 1986-2024	54,900	63,100
Reactors in Construction Pipeline (28 GWe), 1986-2035	21,300	27,700
Total	88,600	103,200

For determining repository disposal requirements based on thermal loading, no credit is taken for increased fuel burnup rates. While extended burnup reduces the amount of spent fuel produced, it increases the heat and radioactivity of the resulting spent fuel. The net effect of extended burnup on the waste disposal system is not yet clear.(16,17) On the other hand, the NWPA capacity limit for the first repository is 70,000 MTU, regardless of burnup.

Other developments could result in either higher or lower discharges under the No New Orders case. There is currently interest in the electric utility industry about extending reactor lifetimes to 50 years, or longer.(20) A 50 year reactor lifetime and extended burnup would result in discharges totalling 105,750 MTU. Conversely, if reactor lifetimes are limited to only 30 years and no increased burnup is assumed, then spent fuel discharges could amount to 78,700 MTU.

Defense High-Level Radioactive Waste

One of the major uncertainties in planning a national high level radioactive waste disposal system is the amount of defense wastes which will require geologic disposal. DOE annually publishes defense high level waste inventories and projections as part of the Integrated Data Base prepared by Oak Ridge National Laboratory. Most defense high level waste is presently stored in underground tanks as liquid, sludge, slurry, or saltcake. Current and projected volumes by waste form are presented in Table III. The defense high level waste will be solidified in borosilicate glass before disposal in a geologic repository. A processing facility is already under construction for this purpose at the Savannah River plant, and is expected to produce about 7,400 canisters by 2020.(26) According to the Oak Ridge projections, the solidified wastes at Savannah River would represent about 1 percent of the projected total defense waste volume in 2020, but would contain almost 25 percent of the total radioactivity. DOE assumes that two canisters of defense waste equal one MTU of civilian spent fuel.

Table III
Current (1985) and Projected (2020) Inventories
of Defense High-Level Radioactive Waste, by Waste Form

Waste Form	Volume ($10^3 m^3$) Current (1985)	Volume ($10^3 m^3$) Projected (2020)	Radioactivity (10^6Ci) Current (1985)	Radioactivity (10^6Ci) Projected (2020)	Thermal Power (10^3W) Current (1985)	Thermal Power (10^3W) Projected (2020)
Liquid	106.7	52.7	141.4	98.1	403.0	302.9
Sludge	59.8	48.5	691.3	595.7	2,210.4	1,932.5
Salt Cake	130.6	115.6	200.4	64.2	528.3	167.4
Slurry	54.8	133.9	135.0	136.3	460.3	395.7
Calcine	3.0	23.5	47.7	446.2	137.4	1,310.0
Capsules	(A)	(A)	212.0	93.4	581.5	255.7
Glass	0.0	4.6	0.0	486.4	0.0	1,384.6
TOTAL	354.9	378.8	1,427.8	1,920.3	4,320.9	5,748.8

A - Less than $100m^3$.

Ref. 26

In estimating the amount of repository capacity required for disposal of defense high level waste, DOE has offered figures ranging from 16,000 to 20,000 canisters, equivalent to 8,000-10,000 MTU. (See Table IV) These estimates apparently do not include a large amount of older waste stored in single-shell tanks at Hanford, Washington.(27, 28, 29, 30) Additionally, there are uncertainties about the amount of canisters that will be required for final disposal of high level waste at the Idaho Chemical Processing Plant, where liquid reprocessing wastes are presently converted to a dry calcine for interim storage. Other unknowns include future N-Reactor operation at Hanford, and the potential for international arms control developments, or the lack thereof. In response to a request from the U.S. General Accounting Office (GAO), DOE's Office of Defense Programs prepared a maximum case defense waste projection. This waste projection (see Table IV) has 55,000 canisters, equivalent to about 27,500 MTU, resulting from defense activities through the year 2020. Given the uncertainties regarding future defense activities, the most appropriate figure for planning purposes is the DOE maximum case projection developed for the GAO.(10)

Table IV
Forecasts of Defense High-Level Radioactive Waste Requiring Geologic Disposal in 2020

Report	Canisters	Metric Tons of Uranium
DOE, Mission Plan, June 1985	16,000	8,000
DOE, Evaluation of Commercial Repository Capacity, June 1985	20,000	10,000
GAO, Issues Concerning *Postponement of Second* Repository, July 1986		
Base Case	16,000	8,000
Augmented Case	33,000	16,500
Maximum Case	55,000	27,500

Refs. 4, 10, and 21.

Combined Civilian and Defense High Level Radioactive Waste

Table V summarizes total civilian and defense radioactive waste requiring geologic disposal in metric tons of uranium (MTU) or its equivalent. Civilian spent fuel discharges for the No New Orders case, assuming no increase in fuel burnup, are 103,200 MTU, based on Table II. Civilian reprocessing waste requiring geologic disposal is estimated at 650 MTU, representing the waste currently in storage at the former Nuclear Fuel Service facility at West Valley, New York, and assuming no additional civilian reprocessing.(5) Defense high level radioactive waste requiring geologic disposal is 55,000 canisters, or the equivalent of 27,500 MTU, based on the DOE/GAO maximum case projections through the year 2020. This produces a total of approximately 131,350 MTU requiring geologic disposal. In addition, less than 1,000 MTU of miscellaneous high level waste is also expected.(26)

Table V
Spent Fuel and High-Level Radioactive Waste Requiring Geologic Disposal

Waste Type	Metric Tons of Uranium
Civilian Spent Fuel ("No New Orders" Case, No Increased Fuel Burn Up)	103,200
Civilian High-Level Waste (No additional Civilian Reprocessing)	650
Defense High-Level Waste (Maximum Case through year 2020)	27,500
Total	131,350

GEOTECHNICAL CONSTRAINTS ON REPOSITORY CAPACITY

The concept of deep geologic disposal of high level radioactive waste centers around the construction of a deep mine with a high heat flow. DOE's final guidelines for the selection of repository sites establish rock characteristics relevant for determining the acceptability for the potential site. (10 CFR sec. 960.5-2-9) Principally, a potential site must have a rock interval of sufficient vertical and lateral extent so as to accommodate a repository, the rocks to be excavated are of such condition that construction in the repository poses no "undue hazard," and the construction of a repository in such rocks is both technically and financially feasible.

Repository Capacity Constraints of Nominated Sites

The final environmental assessments (EAs) prepared for the first repository site nominations as required by NWPA, describe specific sites in three geologic media--basalt, welded tuff, and salt. The EAs address the broad range of concerns in section 960.502-9(a) of the siting guidelines, concluding that, although the five sites are different in terms of their gross rock characteristics, all five sites do meet the basic qualifying conditions of the size, construction feasibility and cost feasibility. With one exception, the favorable condition described in section 960.5-2-9(a)(1), which deals with rock body size at any one site being sufficient to allow on-site flexibility in ultimate repository location, is also met by the sites nominated by the Secretary of DOE for the first repository on May 28, 1986.

Hanford, Washington. The Reference Repository Location extends over 10,000 acres in the west-central part of the 570-square-mile Hanford Reservation in the State of Washington. The principal geologic unit of interest is the Cohasset flow in the 15-million-year-old Grande Ronde basalt within the Columbia River Basalt Group. The Cohasset flow is 240 to 266 feet thick and lies 2,850 to 3,100 feet below the ground surface. No significant geologic structures limit the lateral extent of the Cohasset flow in the vicinity of the repository location.(34)

The design repository is based on the detailed repository underground layout study, which provides for a subsurface areal extent of 1,978 acres using a single container per borehole emplacement concept. Considering the approximate thermal load of 1.2 kilowatts of thermal energy per metric ton of uranium (kW/MTU), equivalent to one spent fuel assembly from a pressurized water reactor per waste package, the overall thermal loading for the Hanford site is 70 kW/acre. The thermal loading assumes spent fuel ten years out of reactor, and no increase in burnup rate. (See Table VI for a summary of these parameters for the Hanford site, as well as for the other four nominated sites discussed below.)

Yucca Mountain, Nevada. The Yucca Mountain site is located 85 miles northwest of Las Vegas in the southwest corner of the Nevada Test Site. The principal geologic unit of interest in the Topopah Spring member of the 13 million-year-old Paintbrush Tuff Formation. The Topopah Spring member is a welded tuff formed from several volcanic ash flows. It is about 1,150 feet thick and extends over an area of 1,850 acres within the primary repository area. The primary area is bounded on the east and west by major faults. Several possible repository expansion areas, totaling about 6,800 acres in extent, lie to the north, east, and west of the primary repository area. These secondary areas have not, to date, been thoroughly investigated.(37)

Table VI
Sites Nominated for First Repository Characterization

Site	Geologic Media	Geologic Unit	Subsurface Extent of Design Repository (acres)	Apparent Overall Thermal Loading (kW/acre)	Subsurface Area Available (acres)
Hanford	Basalt	Cohasset flow, Grande Ronde Basalt	2,000	70	10,000
Yucca Mountain	Welded Tuff	Topopah Spring Member, Paintbrush Tuff	1,520	55	1,850 (Principal Area) + 6,800 (Secondary Areas)
Deaf Smith	Bedded Salt	Lower San Andres Unit 4	2,240	38	5,760
Richton	Domal Salt	Richton Dome	2,020	42	5,440
Davis Canyon	Bedded Salt	Salt Cycle 6 of Paradox Formation	1,930	44	5,760

Refs. 23, 34, 35, 36, and 37.

The design repository would extend over 1,520 subsurface acres at a depth of 750 feet below ground surface. The apparent overall thermal loading provided by a 70,000 MTU repository at 1.2 kW/MTU is about 55 kW/acre. The limited extent of the primary repository areas and the uncertainty related to characterization of the secondary areas indicate that the favorable condition related to site location and flexibility in the siting guidelines at section 960.5-2-9(e)(1), is not met at Yucca Mountain. While it appears technically possible to construct a repository with a capacity of 140,000 MTU at Yucca Mountain, the information available in the EA suggests a high degree of uncertainty about emplacing more than 100,000 MTU at the site.

Deaf Smith County, Texas. This potential first repository site is located in Deaf Smith County, in the panhandle of northern Texas. The geologic unit under evaluation is the Lower San Andres Unit 4 and, in particular, a 160-feet thick salt horizon within the 250-feet-thick Unit 4. The interval of interest occurs at about 2,500 feet below the ground surface. Regional isopach maps of Unit 4 and the salt horizon within it indicates no significant constraints in the overall vertical and lateral extent of the salt.(33)

The reference repository design requires 2,240 acres of subsurface extent at a depth of 2,570 feet below the land surface. Because of the far-field thermal effects related to emplacement of heat sources within salt, that is the anticipated uplift of several meters of the ground surface over a salt-hosted repository, the overall thermal loading in salt is limited to approximately 40 kW/acre. Whereas surface facilities and the surface controlled areas extend for only nine square miles (5,760 acres) there appears to be no geologic constraint on the sub-surface extent of the potential host salt horizon.

Richton Dome, Mississippi. The Richton Dome, in southern Mississippi, is a large salt diapir projecting upwards into Miocene-age sediments from deeply buried Jurassic Louann Salt. The shape of the Richton Dome varies from markedly elongate depths of 19,000 feet below the land surface to slightly elongate (northeast-to-southwest) at a depth of 650 feet. At the proposed repository depth of 2,120 feet, the Richton Dome has an areal extent of about 5,400 acres.(36)

The reference repository design calls for 2,020 acres of underground development, which yields an apparent thermal loading of 42 kW/acre. The limits on thermal loading constrain the emplacement density of the waste packages but the vast vertical and lateral extent of the Richton Dome offers no significant geologic constraint on repository capacity or location.

Davis Canyon, Utah. The Davis Canyon site is located in southeastern Utah just east of Canyonlands National Park. The geologic unit considered for construction of a high-level radioactive waste repository is Salt Cycle 6 of the Pennsylvanian-age Parodox Formation. Salt Cycle 6 ranges from 172 to 252 feet in thickness within the vicinity of the site. The repository horizon is proposed at 3,015 feet below the ground surface.(35)

The reference repository design requires 1,930 acres of underground development area in a 9-square mile (5,760 acres) area that corresponds to the extent of the controlled area at the surface location of the repository facilities. The apparent overall thermal loading for a 70,000 MTU repository at Davis Canyon is approximately 44 kW/acre. There is no apparent geologic constraint on the vertical and lateral extent of Salt Cycle 6 within the immediate vicinity of the Davis Canyon site.

Generic Repository Capacities

For comparative purposes, it is useful to look at generic (non-site specific) repositories constructed in different geologic media (see Table VII). In such comparisons, the thermal conductivity of the principal rock type is the fundamental thermo-mechanical parameter governing ultimate repository capacities.

Repositories constructed in basalt have a conservative near-field thermal limit, determined by rock stress considerations, of about 70 kW/acre.(9) Granite, because of its higher thermal conductivity, has a near-field thermal limit of about 90 kW/acre for a repository comprised of 50 percent spent fuel and 50 percent civilian high-level waste.(38) The local thermal loading capacity of welded tuff ranges from 57 kW/acre to 80 kW/acre.(9) Salt, as a result of its tendency to flow under thermal stress and its low thermal conductivity, has a far-field thermal limit that is restricted to about 40 kW/acre.(31)

Table VII
Generic Repository Capacities

	Geologic Media			
	Basalt	Salt	Tuff	Granite
Emplacement Area, 70,000 MTU Repository (acres)	1,200	2,100	1,475/1,050	935
Emplacement Area, 140,000 MTU Repository (acres)	2,400	4,200	2,950/2,100	1,870
Approximate Thermal Load (kW/MTU)	1.2	1.2	1.2	1.2
Overall Thermal Loading (kW/acre)	70	40	57/80	90

Refs. 3, 9, and 38.

The near-field thermal limit, which reflects the behavior of the geologic media under the stress induced by emplacement of hot waste packages is the principal constraint on repository loading, except for salt. For salt, far-field thermal limits are the important thermal constraint, but design repository local areal thermal loading of about 40 kW/acre is within far-field thermal limit considerations.(3) For granite, basalt and tuff the effect of thermal loading on rock strength considerations, reflected in the near-field thermal loading, is the principal concern for repository design. The high thermal conductivity of these geologic media permits greater local area thermal loading.

Table VII illustrates the minimal repository area requirements for generic repositories constructed in basalt, salt, tuff, and granite. Using a nominal thermal load of 1.2 kW/MTU, a 70,000 MTU repository and a 140,000 MTU repository can be scaled with subsurface areal extent ranging from a low of 935 acres/ 1,870 acres (70,000 MTU/140,000 MTU) for granite to 2,100 acres/4,200 acres for repositories of similar capacity constructed in salt.

The focus of concern over geologic constraints on repository capacities centers on sec. 960.5-2-9, Rock Characteristics, of the repository siting guidelines. An examination of the five sites nominated by DOE and a generic site in crystalline rock (granite) indicate that only the Yucca Mountain site in Nevada appears to present any geotechnical limitation on repository (see Table VIII). Even the Yucca Mountain site with the addition of 6,800 acres in its secondary areas may well have sufficient extent to handle all of the spent fuel, civilian high-level, and defense radioactive waste anticipated in the most realistic scenarios for total disposal requirements.

Moreover, additional pre-emplacement cooling of 20-40 years could substantially increase repository design capacity, lowering the anticipated thermal loading by 40 percent or more.(38) Such additional pre-emplacement cooling could occur either at reactor sites or at a monitored retrievable storage (MRS) facility.(18, 19)

Table VIII
Potential for 140,000 MTU Capacity Repository
Based On Geologic Constraints

Site	Geologic Media	Favorable Conditions As Per Section 960.5-2-9 (1)	Available Subsurface Area Relative to Requirement for 140,000 MTU Repository
Hanford	Basalt	Present	Much Larger
Yucca Mountain	Welded Tuff	Not Present	About Same
Deaf Smith	Bedded Salt	Present	Larger
Richton	Domal Salt	Present	Larger
Davis Canyon	Bedded Salt	Present	Larger
Generic	Granite	Assumed Present	Larger

Refs. 33, 34, 35, 36, 37, and 38.

CONCLUSIONS AND RECOMMENDATIONS

This overview of high level radioactive waste projections and repository disposal capacity results in three major conclusions. First, the projected disposal requirements for civilian spent fuel, civilian high level waste, and defense high level radioactive waste are less than 140,000 MTU. Second, the five sites recommended for the first repository, along with the generic granite sites under consideration for the second repository, all appear capable of accommodating up to 140,000 MTU. The one possible exception is the site at Yucca Mountain, Nevada, where construction of a repository for 140,000 MTU would require expansion into a nearby rock formation. Third, there does not appear to be a need for more than one repository based on disposal capacity requirements. To the extent that more than one repository is required, the case must be based on reasons other than repository capacity, for example, on issues such as regional equity, technical redundancy or systemwide transportation impacts.

Based on the findings and conclusions of this paper, the following recommendations are offered for the assessment of disposal capacity requirements and its use in systems planning. First, the waste disposal system should be planned on the basis of disposal requirements resulting from the No New Orders case for civilian nuclear power and the maximum case developed for defense high level waste. The potential reduction in the amount of spent fuel resulting from extended burnup should be ignored in calculating repository disposal requirements, because the increased thermal loading of the resulting spent fuel may offset the reduction in the amount of spent fuel. Second, the nuclear waste disposal system should be planned around one geologic repository with a capacity of approximately 140,000 MTU. If a second repository should be needed, it will not be needed until well after the third decade of the next century, which allows ample time for planning. Third, in the selection of repository candidate sites, the ability to accommodate up to 140,000 MTU capacity should be explicitly considered. This would require amending DOE's site selection guidelines. Fourth, greater consideration should be given to increased pre-emplacement cooling time either at reactors or at a monitored retrievable storage (MRS) facility.

REFERENCES

1. U.S. DEPARTMENT OF ENERGY, "Draft Mission Plan Amendment," DOE/RW-0128 (January 1987).

2. U.S. DEPARTMENT OF ENERGY, "Report to the President by the Interagency Review Group on Nuclear Waste Management," TID-29442 (March 1979).

3. U.S. DEPARTMENT OF ENERGY, "Final Environmental Impact Statement: Management of Commercially Generated Radioactive Waste," DOE/EIS-0046F, Vols. 1-3 (October 1980).

4. U.S. DEPARTMENT OF ENERGY, "Mission Plan for the Civilian Radioactive Waste Management Program," DOE/RW-0005, Vols. 1-3 (June 1985).

5. U.S. DEPARTMENT OF ENERGY, "Final Environmental Impact Statement: Long-Term Management of Liquid High-Level Radioactive Waste Stored at the Western New York Nuclear Service Center, West Valley," DOE/EIS-0081 (June 1982).

6. U.S. GENERAL ACCOUNTING OFFICE, "Return of Spent Nuclear Fuel from Foreign Research Reactors to the United States," RCED-85-47 (December 1984).

7. U.S. DEPARTMENT OF ENERGY, "Commercial Nuclear Power: Prospects for the United States and the World," DOE/EIA-0438 (86).

8. U.S. DEPARTMENT OF ENERGY, "World Nuclear Fuel Cycle Requirements, 1986," DOE/EIA-0436 (86).

9. PACIFIC NORTHWEST LABORATORY, "Considerations Bearing on the Timing for a Second Geologic Repository," Draft Report Prepared for the U.S. Department of Energy under Contract DE-AC06-76RLO-1830 (May 16, 1986).

10. U.S. GENERAL ACCOUNTING OFFICE, "Nuclear Waste: Issues Concerning DOE's Postponement of Second Repository Siting Activities," RCED-86-200FS (July 1986).

11. U. S. DEPARTMENT OF ENERGY, "Spent Fuel Storage Requirements," DOE/RL-81-1 (May 1984).

12. PACIFIC NORTHWEST LABORATORY, "Reactor-Specific Spent Fuel Discharge Projections: 1984 To 2020," PNL-5396 (April 1985).

13. STATE OF TENNESSEE "Evaluation of the Need, Feasibility, and Siting of the MRS in Tennessee," Draft Final Report (December 1985).

14. STATE OF MINNESOTA, "Summary of High-Level Radioactive Waste Projections and Implications for Second Repository Need and Timing," (July 1986).

15. U.S. DEPARTMENT OF ENERGY, "Energy Forecasts for 1985," DOE/EIA-0495.

16. BATTELLE MEMORIAL INSTITUTE, OFFICE OF NUCLEAR WASTE ISOLATION, "Spent Fuel Burnup and Age: Implications for the Design and Cost of a Waste Disposal System," BMI/ONWI-561 (December 1984).

17. ROY F. WESTON, INC., "The Effects of Extended Nuclear Fuel Burn Up on the Waste Management System," Report Prepared for the U.S. Department of Energy Under Contract No. DE-AC01-83-NE-44301 (March 1985).

18. ALLIED-GENERAL NUCLEAR SERVICES, "Impacts of Extended Advanced Spent Fuel Storage on Reprocessing," EPRI, NP-3682 (August 1984).

19. PACIFIC NORTHWEST LABORATORIES, "Surveillance of LWR Spent Fuel in Wet Storage," EPRI, NP-3765 (October 1984).

20. OAK RIDGE ASSOCIATED UNIVERSITIES, "The Longevity of Nuclear Power Systems," EPRI, NP-4208 (August 1985).

21. U.S. DEPARTMENT OF ENERGY, "An Evaluation of Commercial Repository Capacity for the Disposal of Defense High-Level Waste," DOE/DP/0020/1 (June 1985).

22. U.S. DEPARTMENT OF ENERGY, "Notice of Inquiry: Calculating Nuclear Waste Fund Disposal Fees for DOE Defense Program Waste; Inquiry and Request for Public Comment," Docket No. OCRWM/NOI-86-101 (December 1986).

23. OAK RIDGE NATIONAL LABORATORIES, "Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/NE-0017-2 (September 1983).

24. OAK RIDGE NATIONAL LABORATORIES, "Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/RW-0006 (September 1984).

25. OAK RIDGE NATIONAL LABORATORIES, "Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/RW-0006, Rev. 1 (December 1985).

26. OAK RIDGE NATIONAL LABORATORIES, "Integrated Database for 1986: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics," DOE/RW-0006, Rev. 2 (September 1986).

27. WASHINGTON STATE INSTITUTE FOR PUBLIC POLICY, "Defense Radioactive Waste: Some Questions and Answers," Nuclear Waste Information Report 86-1 (January 1986).

28. STATE OF WASHINGTON, "Comments on Calculating Nuclear Waste Fund Disposal Fees for DOE Defense Waste," (January 26, 1987).

29. U.S. DEPARTMENT OF ENERGY, "Draft Environmental Impact Statement: Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes," DOE/EIS-0113, Vols. 1-3 (March 1986).

30. U.S. GENERAL ACCOUNTING OFFICE, "Nuclear Waste: Unresolved Issues Concerning Hanford's Waste Management Practices," RCED-87-30 (November 1986).

31. BATTELLE MEMORIAL INSTITUTE, "Limits on the Thermal Energy Release from Radioactive Waste in a Mined Geologic Repository," ONI-4 (March 1983).

32. BATTELLE MEMORIAL INSTITUTE, "Preliminary Thermomechanical Analysis of a Conceptual Nuclear Waste Repository at Four Salt Sites," BMI/ONWI-512 (July 1986).

33. U.S. DEPARTMENT OF ENERGY, "Environmental Assessment, Deaf Smith County Site, Texas," DOE/RW-0069, Vols. 1-2 (May 1986).

34. U.S. DEPARTMENT OF ENERGY, "Environmental Assessment, Reference Repository Location, Hanford Site, Washington," DOE/RW-0070, Vols. 1-2 (May 1986).

35. U.S. DEPARTMENT OF ENERGY, "Environmental Assessment, Davis Canyon Site, Utah," DOE/RW-0071, Vols. 1-2 (May 1986).

36. U.S. DEPARTMENT OF ENERGY, "Environmental Assessment, Richton Dome Site, Mississippi," DOE/RW-0072, Vols. 1-2 (May 1986).

37. U.S. DEPARTMENT OF ENERGY, "Environmental Assessment, Yucca Mountain Site, Nevada Research and Development Area, Nevada," DOE/RW-0073, Vols. 1-2 (May 1986).

38. BATTELLE MEMORIAL INSTITUTE, "Typical Repository Conditions for Generic Commercial and Defense High-Level Nuclear Waste and Spent Fuel Repositories in Crystalline Rock," BMI/OCRD-12, Rev. 1 (January 1986).