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ROUGH DRAFT

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DEVELOPMENT OF REFERENCE CONDITIONS FOR GEOLOGIC REPOSITORIES FOR NUCLEAR WASTE IN THE USA†

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MASTER

1. Introduction

This paper summarizes activities to determine interim reference conditions for temperatures, pressure, fluid, chemical, and radiation environments that are expected to exist in commercial and defense high-level nuclear waste and spent fuel repositories in salt, basalt, tuff, granite and shale. These interim conditions are being generated by the Reference Repository Conditions Interface Working Groups (RRC-IWG), an ad hoc IWG established by the National Waste Terminal Storage Program's (NWTS) Isolation Interface Control Board (I-ICB). Members of the RRC-IWG are:

G. E. Raines, ONWI, Chairman
H. C. Claiborne, ORNL, Salt Repository Environment
K. H. Henry, Rockwell (BWIP), Basalt Repository Environment
N. Hubbard, ONWI, Geochemical Environment
T. O. Hunter, SNL (WIPP), Salt Repository Environment
R. W. Lynch, SNL (NNWSI), Tuff Repository Environment
J. L. McElroy, PNL, Commercial High-Level Waste
J. D. Osnes, RE/SPEC, Granite Repository Environment
L. D. Rickertsen, SAI, Shale Repository Environment
N. E. Bibler, SRL, Defense High-Level Waste

The reference repository conditions being developed are intended to serve as a guide for: a) scientists conducting material performance tests; b) engineers preparing the design of

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repositories; c) the technically conservative conditions to be used as a basis for DOE license applications; and d) scientists and engineers developing waste forms. Present plans call for the completion of generic reference repository conditions for salt, basalt, tuff, granite, and shale by December, 1981. Interim conditions for the five rock types will be published as ONWI reports in the near future.

2. Reference Canistered High-Level Wastes

Three types of waste are being considered in this effort: spent fuel (SF) from light water reactors, commercial high-level waste (CHLW) that would result from reprocessing of light water reactor fuel, and defense high-level waste (DHLW). The specific choice of wastes used in the calculations was based on the goal of conservatism, i.e., overprediction of temperatures which will actually occur in the repositories. Thus, Pressurized Water Reactor (PWR) spent fuel was chosen over Boiling Water Reactor (BWR) spent fuel because of its greater thermal impact. CHLW resulting from a 3:1 mix of wastes from fresh UO_2 and MOX fuel was chosen over wastes from fresh UO_2 fuel only. The maximum thermal output DHLW described by Savannah River Laboratory[1] was selected over Hanford wastes or other SRP wastes. Characteristics of the canistered reference wastes are given in Tables 1 and 2.

TABLE 1. Relative Heat-Generation Rates of Reference SF,[a] CHLW,[b] and DHLW[c]

Year After Emplacement[d]	SF	CHLW	DHLW
0	1.000	1.000	1.000
5	.838	.810	.886
10	.750	.692	.789
15	.681	.600	.705
20	.622	.529	.630
30	.525	.402	.505
40	.449	.313	.407
50	.387	.246	.330
70	.301	.157	.191
100	.238	.0864	.128
190	.137	.0296	.032
290	.108	.0215	.013
390	.0919	.0163	.0072
490	.0806	.0145	.0047
990	.0466	.00810	.0021
1990	.0247	.00404	.0013
5990	.0148	.00230	.0009
9990	.0114	.00175	.0008

(a) Pressurized Water Reactor fuel; 33,000 MWd/MTU burnup.

(b) See Y/OWI/TM-34, "Nuclear Waste Projections and Source Term Data for FY 1977." The CHLW decay rates correspond to waste arising from fuel which is a 3:1 mix of fresh UO_2 and MOX fuels.

(c) E. I. DuPont de Nemours and Co., "Preliminary Technical Data Summary No. 3," DPSTD-77-13-3 (1980).

(d) Assumes commercial waste (SF or CHLW) is 10 years out of reactor at emplacement; DHLW is 15 years out of reactor at emplacement.

TABLE 2. Description of Reference Canistered Waste

Characteristics	SF	CHLW	DHLW
Waste Description			
Active Length (m)	3.7	2.4	2.3
Active Volume (m^3)	NA	0.18	0.63
Age of Waste (yr)	10^a	10^a	15^a
Thermal Loading (kW/canister)	0.55^b	2.16^c or 1.0^d	0.31^e
Canister Dimensions			
Outer Diameter (cm)	35.6^f	32.4^g	61.0^h
Inner Diameter (cm)	33.7	30.5	59.1
Length (m)	4.7	3.0	3.0
Materials			
Waste	UO_2[j]	Glass[j]	Glass[j]
Filler in Canister	Helium	Air	Air
Canister	Carbon Steel	304L Stainless Steel	304L Stainless Steel

(a) At emplacement (years after discharge from reactor)

(b) Heat generation rate for a single PWR assembly 10 years out of the reactor. BWR assemblies would have a lower heat generation rate but this value has been chosen as its use results in predicting maximum temperatures in the repository.

(c) Heat generation rates for CHLW used in salt and tuff studies to date.

(d) Heat generation rate for CHLW used in granite and shales studies to date.

(e) Maximum expected thermal loading for Savannah River Plant wastes; many canisters will have a lower loading.

(f) Nominal 14-inch schedule 30 carbon steel pipe

(g) Nominal 12-inch schedule 40s 304L stainless steel pipe

(h) Nominal 24-inch schedule 20 304L stainless steel pipe

(j) The choice of waste form for these calculations was based on their advanced state of engineering development. The calculated environments outside the waste forms are insensitive to the details of the waste forms themselves other than heat output and physical dimensions.

3. Geologic Media Investigated

The geologic media for which reference conditions are being established include salt, basalt, tuff, granite, and shale. These media were identified as having the most pressing need because of present NWTS emphasis and ongoing repository projects.

a. Salt. Bedded deposits of salt are true sedimentary rocks that differ from other sediments in that salt and other evaporites accumulated on the sea floor through chemical precipitation rather than by physical or organic deposition. The process of formation produces rock salt (halite) that is comprised of closely bound aggregates of irregularly shaped single crystals of relatively high purity that may exceed 99% NaCl. A number of mineral impurities can be present such as anhydrite and polyhalite and clays that are mostly distributed at the grain boundaries.

Thick layers of rock salt are now preserved in an undisturbed condition in many sedimentary basins where the salt is buried beneath younger sediments. In other basins, however, the salt has been deformed and has flowed to form a series of salt domes, salt anticlines, salt ridges, and salt pillows. These salt structures are commonly diapiric; that is, the plastic core of salt has pierced the overlying or surrounding rocks.

The interior salt domes in the Gulf Coast basin and the bedded salt in the Permian and other basins in the U.S. are being evaluated as potential sites for nuclear waste repositories. Dome salt is usually of higher purity and is more massive in the vertical extent than bedded salt. Bedded salt has interbeddings of other rocks such as shale and limestone and frequently contains a small percentage of brine inclusions that occur to a lesser degree in dome salt. However, dome salt can have regions containing relatively high concentration of the evaporites in a non-layered structure.

Some of the properties of rock salt that led to its consideration as a disposal medium include:

1. Salt deposits are located in tectonically stable regions.
2. Rock salt formations have been protected from circulating ground waters for tens of millions of years.
3. Rock salt has a relatively high thermal conductivity for more rapid heat dissipation.
4. Rock salt flows plastically at relatively low temperatures and pressure which will relieve stress concentration and cause self-healing of any fractures that might develop.

Studies of the expected repository environments for salt are being conducted by ORNL under contract to the Office of Nuclear Waste Isolation.

b. Basalt. Studies of the expected repository environments for basalt are being conducted by the Basalt Waste Isolation Project (BWIP) of Rockwell Hanford Operations (Rockwell) for the Department of Energy (DOE). These studies focus on the flood-basalt formations underlying the Hanford Site in southeastern Washington.

Basalt is a hard, dense volcanic rock formed by cooling of lava flows. The basalt underlying the Hanford Site is part of a large accumulation of lava flows called the Columbia River Basalt Group, which extends over an area of approximately 200,000 square kilometers. The Hanford Site is located within the Pasco Basin, where the accumulation of Columbia River Basalt flows and interbedded sediments attains its maximum known total thickness of over 1,500 meters. Individual Columbia River Basalt flows vary in thickness up to a maximum of over 90 meters, with an average thickness of about 22 to 36 meters.

Within the candidate site area, the Columbia River Basalt Group consists of three formations; primary candidates for a repository host rock are within the Grand Ronde Basalt, which is the oldest and deepest of the three formations. Of the over 30 flows within the Grand Ronde Basalt formation, the Umtanum flow is currently favored for repository siting. The upper portion of each flow is vesicular, with vesicularity increasing toward the flow top; however, flow interiors, which are two-thirds to three-quarters of total flow thicknesses, consist of the dense, although jointed, basalt judged best for repository construction because of its low permeability and high mechanical strength.

Variable thicknesses of lower density (higher porosity) interflow zones lie between the dense basalt flows. The interflow zones are the principal water-bearing portions of the basalt formations. Lateral groundwater movement within interflow zones is relatively unrestricted; however, the degree of vertical groundwater movement between interflow zones is limited by the relative impermeability of the dense basalt flows.

c. Tuff. Tuff is a general term applied to a wide variety of rocks composed of consolidated fragmental volcanic materials that result from explosive volcanic eruptions. The most voluminous tuffs, and those of principal interest to the NWTS, are derived from silicic magmas, which have bulk chemical compositions similar to those of granite. The mode of eruption and emplacement is the basis for distinguishing between two primary types of tuff, ash-fall and ash-flow. Depending on depositional conditions the ash-flow tuffs may exhibit various degrees of flattening and fusing, called welding. Resulting thermal and mechanical properties can vary widely, with the highly welded tuffs exhibiting the greatest thermal conductivity and mechanical strength. In general, tuffs have substantial porosity and their thermal properties depend strongly on whether the pores are filled with water.

Studies of the expected repository environments for tuff are being conducted by Nevada Nuclear Waste Storage Investigations (NNWSI) project participants and focus strongly on conditions as they might be expected in the southwestern portion of the Nevada Test Site (NTS).

d. Granite. Granite is a hard, crystalline, silicate rock originating at high temperature and pressure below the earth's surface. It is composed primarily of quartz and potassium feldspar with subordinate amounts of sodic plagioclase, biotite, hornblende, or muscovite. Classification of granitic rocks is based upon relative proportions of plagioclase and potassium feldspar. The high pressure and crystallization temperature and the slow cooling rate at which granitic plutons form affect the mineralogical detail of these rocks. Granite was selected for consideration as a possible host rock for a repository because of its occurrence in large, uniform masses in the earth's crust, high mechanical strength properties, chemical stability, and small intrinsic value.

Studies of the expected repository environments for granite are being conducted by RE/SPEC, Inc. under contract to the Office of Nuclear Waste Isolation.

e. Shale. Sedimentary shale deposits can be found in most regions of the United States. Thick sequences can be found at great depths in most of these locations. At depth the rock tends to have uniform properties with widely spaced joints. Many formations have been identified which have been stable longer than the half-life of the longest lived waste nuclides. The primary advantages of shale for a repository are its very low permeability and its relatively high sorption capability. These properties may be modified locally as a result of heat generation in a repository, but, in general, the formation is expected to maintain excellent fluid immobilization and waste retention capabilities.

Studies of the expected repository environments for shales are being conducted by SAI, Inc. under contract to the Office of Nuclear Waste Isolation.

4.0 Reference Repository Description

The bases selected for calculation of reference repository conditions in salt, basalt, tuff, granite and shale are given in Table 3. These descriptions are based on the standard room and pillar mined repository concept. In this concept, storage rooms are excavated deep in the rock and vertical emplacement holes are drilled in rows down the floor. Waste packages are emplaced in the holes and the holes are then backfilled and plugged with a concrete or other shielding plug. The variation in design parameters selected for the various repositories in the five rock types reflects the variation in heat dissipation and rock strength properties for the different media as well as the different heat generation rates for the different waste types. There will undoubtedly be some evolution in these bases before the final reference conditions are selected. The impacts of changes to these design parameters or of other repository design concepts will be reported in future communications of the committee.

It should also be noted that since final designs do not exist for engineered barriers for the repositories in the several rock types, relatively simple geometries had to be assumed for the waste package configurations in the repository environments calculations. These geometries were not the same for all rock types and one of the major improvements desired in the final reference repository conditions reports will be the incorporation of more prototypic waste packages in the calculations.

5. Results

The full compliment of interim reference conditions for all rock types being investigated cannot be presented in this brief paper. Interim reference conditions for a CHLW and an SF repository in salt are discussed in References 2 and 3. Interim reference conditions for repositories in the four other rock types will be published as ONWI reports in the near future. Nevertheless, some illustrative examples are warranted and we have drawn largely on Reference 3 for these.

TABLE 3. REFERENCE REPOSITORY DESCRIPTION

Host Rock	Repository Characteristics	SF	CHLW	DHLW
Salt	Repository Depth Below Surface (m)	600	600	600
	Storage Room Width (m)	5.5	5.5	5.5
	Storage Room Height (m)	6.4	5.5	5.5
	Adjacent Pillar Width (m)	21.3	18.3	18
	Canister Rows per Room	2	1	2
	Row Separation (m)	1.67	---	2.29
	Hole Pitch (along row) (m)	1.67	3.66	2.29
	Canisters per Hole	1	1	1
	Canister Thermal Loading (kW)[a]	0.55	2.16	0.31
	Local Areal Thermal Loading (W/m^2)[a]	25	25	11.6
	Average Areal Thermal Loading (W/m^2)[a]	15	< 25	< 11.6
	Emplacement Hole Depth (m)	6.25	5.5	5.5
	Emplacement Hole Diameter (cm)	0.54	0.54	0.76
	Hole Liner Dimensions			
	Outer Diameter (cm)	53.3	53.3	
	Inner Diameter (cm)	50.8	50.8	
	Length (m)	6.25	5.5	
	Backfill Dimensions			
	Thickness (cm)	5.1	5.1	
	Length (m)	5	5	
	Overpack Dimensions			
	Outer Diameter (cm)	40.6[b]	40.6[b]	---
	Inner Diameter (cm)	38.1	38.1	---
	Length (m)	5.1	3.4	---
	Materials			
	Overpack	CSt	CSt	---
	Backfill	CSa	CSa	CSa
	Hole Liner	CSt	CSt	CSt
	Emplacement Hole Plug	Ct	Ct	Ct

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[a] At emplacement of wastes

[b] Nominal 16-inch Schedule 40 pipe

CSt = Carbon Steel

CSa = Crushed Salt

Ct = Concrete

TABLE 3 (continued)

Host Rock	Repository Characteristics	SF	CHLW	DHLW
Basalt	Repository Depth Below Surface (m)	1000	(a)	(a)
	Storage Room Width (m)	4.3	(a)	(a)
	Storage Room Height (m)	6.1	(a)	(a)
	Adjacent Pillar Width (m)	32.3	(a)	(a)
	Canister Rows per Room	1	(a)	(a)
	Row Separation (m)	--	(a)	(a)
	Hole Pitch (along row) (m)	3.66[b] or 1.22	(a)	(a)
	Canisters per Hole	1	(a)	(a)
	Canister Thermal Loading (kW)[c]	1.65[b] or 0.55	(a)	(a)
	Local Areal Thermal Loading (W/m^2)[c]	12.3	(a)	(a)
	Average Areal Thermal Loading (W/m^2)[c]	8.2	(a)	(a)
	Emplacement Hole Depth (m)	6.4	(a)	(a)
	Emplacement Hole Diameter (cm)	115.	(a)	(a)
	Hole Liner Dimensions			
	Outer Diameter (cm)	114.3[d]	(a)	(a)
	Inner Diameter (cm)	94.0	(a)	(a)
	Length (m)	6.4	(a)	(a)
	Backfill Dimensions			
	Thickness (cm)	15.2[d]	(a)	(a)
	Length (m)	5.4	(a)	(a)
	Overpack Dimensions			
	Outer Diameter (cm)	53.3[d]	(a)	(a)
	Inner Diameter (cm)	52.8	(a)	(a)
	Length (m)	4.9	(a)	(a)
	Materials			
	Overpack	Ti	(a)	(a)
	Backfill	TBf	(a)	(a)
	Hole Liner	Grt	(a)	(a)
	Emplacement Hole Plug	Ct	(a)	(a)

(a) Not yet available.

(b) For a repository in basalt, two configurations have been calculated; three PWR or seven BWR elements per canister, and one PWR or three BWR elements per canister.

(c) At emplacement of the wastes.

(d) The BWIP Project has developed advanced concepts for waste packages. Their thinking is not adequately treated in this simple table. There is an additional 5 cm air gap between the titanium overpack and the tailored backfill in this design.

Ti = Titanium; TBf = Tailored Backfill; Grt = Grout; Ct = Concrete

TABLE 3 (continued)

Host Rock	Repository Characteristics	SF	CHLW	DHLW
Tuff	Repository Depth Below Surface (m)	800	800	(a)
	Storage Room Width (m)	7.5	5.0	(a)
	Storage Room Height (m)	7.0	5.0	(a)
	Adjacent Pillar Width (m)	30	20	(a)
	Canister Rows per Room	2	1	(a)
	Row Separation (m)	2.5	--	(a)
	Hole Pitch (along row) (m)	1.19	3.50	(a)
	Canisters per Hole	1	1	(a)
	Canister Thermal Loading (kW)[b]	0.55	2.16	(a)
	Local Areal Thermal Loading (W/m^2)[b]	25	25	(a)
	Average Areal Thermal Loading (W/m^2)[b]	< 25	< 25	(a)
	Emplacement Hole Depth (m)	8.0	6.0	(a)
	Emplacement Hole Diameter (cm)	0.41	0.37	(a)
	Hole Liner Dimensions			
	Outer Diameter (cm)	(c)	(c)	(a)
	Inner Diameter (cm)	(c)	(c)	(a)
	Length (m)	(c)	(c)	(a)
	Backfill Dimensions			
	Thickness (cm)	2.5	2.5	(a)
	Length (m)	4.7	3.0	(a)
	Overpack Dimensions			
	Outer Diameter (cm)	(c)	(c)	(a)
	Inner Diameter (cm)	(c)	(c)	(a)
	Length (m)	(c)	(c)	(a)
	Materials			
	Overpack	(c)	(c)	(a)
	Backfill	air	air	(a)
	Hole Liner	(c)	(c)	(a)
	Emplacement Hole Plug	Ct	Ct	(a)

(a) Not yet available.

(b) At emplacement of wastes.

(c) Hole liner, backfill, and overpack were not used in the calculations to determine interim reference conditions for the tuff repositories. A more realistic representation of the waste package is planned for the final reference conditions report.

Ct = Concrete

TABLE 3 (continued)

Host Rock	Repository Characteristics	SF	CHLW	DHLW
Granite	Repository Depth Below Surface (m)	1000	1000	1000
	Storage Room Width (m)	7.5	7.5	7.5
	Storage Room Height (m)	7.0	7.0	7.0
	Adjacent Pillar Width (m)	22.5	22.5	22.5
	Canister Rows per Room	2	2	2
	Row Separation (m)	2.5	2.5	2.5
	Hole Pitch (along row) (m)	1.83	2.67	1.53
	Canisters per Hole	1	1	1
	Canister Thermal Loading (kW)[a]	0.55	1.0	0.31
	Local Areal Thermal Loading (W/m^2)[a]	20	25	13.5
	Average Areal Thermal Loading (W/m^2)[a]	< 20	< 25	< 13.5
	Emplacement Hole Depth (m)	6.7	5.0	5.0
	Emplacement Hole Diameter (cm)	0.56	0.52	0.81
	Hole Liner Dimensions			
	Outer Diameter (cm)	(b)	(b)	(b)
	Inner Diameter (cm)	(b)	(b)	(b)
	Length (m)	(b)	(b)	(b)
	Backfill Dimensions			
	Thickness (cm)	10	10	10
	Length (m)	6.7	5.0	5.0
	Overpack Dimensions			
	Outer Diameter (cm)	(b)	(b)	(b)
	Inner Diameter (cm)	(b)	(b)	(b)
	Length (m)	(b)	(b)	(b)
	Materials			
	Overpack	(b)	(b)	(b)
	Backfill	Bt	CGr	CGr
	Hole Liner	(b)	(b)	(b)
	Emplacement Hole Plug	Bt	CGr	CGr

(a) At emplacement of wastes.

(b) Hole liner and overpack were not included in the calculations to determine interim reference conditions for the granite repositories.

Bt = Bentonite

CGr = Crushed Granite

TABLE 3 (continued)

Host Rock	Repository Characteristics	SF	CHLW	DHLW
Shale	Repository Depth Below Surface (m)	600	600	600
	Storage Room Width (m)	5.5	5.5	5.5
	Storage Room Height (m)	6.4	5.5	5.5
	Adjacent Pillar Width (m)	18	18	18
	Canister Rows per Room	2	1	2
	Row Separation (m)	1.67	--	2.29
	Hole Pitch (along row) (m)	2.34	2.85	2.70
	Canisters per Hole	1	1	1
	Canister Thermal Loading (kW)[a]	0.55	1.0	0.31
	Local Areal Thermal Loading (W/m^2)[a]	10	10	10
	Average Areal Thermal Loading (W/m^2)[a]	8	8	8
	Emplacement Hole Depth (m)	7.0	5.5	5.5
	Emplacement Hole Diameter (cm)	0.51	0.51	0.76
	Hole Liner Dimensions			
	Outer Diameter (cm)	(b)	(b)	(b)
	Inner Diameter (cm)	(b)	(b)	(b)
	Length (m)	(b)	(b)	(b)
	Backfill Dimensions			
	Thickness (cm)	5.1	5.1	7.6
	Length (m)	5.5	4.0	4.0
	Overpack Dimensions			
	Outer Diameter (cm)	40.6[c]	40.6[c]	(b)
	Inner Diameter (cm)	38.1	38.1	(b)
	Length (m)	5.1	3.4	(b)
	Materials			
	Overpack	CSt	CSt	(b)
	Backfill	CSh	CSh	CSh
	Hole Liner	(b)	(b)	(b)
	Emplacement Hole Plug	Ct	Ct	Ct

(a) At emplacement of wastes.

(b) A hole liner was not included in the calculations to determine interim reference conditions for the shale repositories. An overpack was not included for the DHLW calculations.

(c) Nominal 16-inch Schedule 40 carbon steel pipe

CSt = Carbon Steel; CSh = Crushed Shale; Ct = Concrete

a. Thermal Environments. The maximum emplacement hole wall, canister surface, and waste centerline temperature histories for the specified SF and CHLW repositories in salt are shown in Figures 1 and 2.[3] These temperature histories were calculated based on a temperature of 34°C for the undisturbed formation at repository depth. It can be seen that for either repository, the maximum salt temperature is less than 160°C or about 90°C below the lowest reported [4] decrepitation temperature for salt samples. In the CHLW repository the temperature of the canister peaks at 260°C a few years after emplacement and decreases to less than 120°C at 100 years. The centerline temperature of the glass peaks at about 320°C at 1-2 years after emplacement and decreases to about 120°C at 100 years. In the SF repository the canister reaches a maximum temperature of about 140°C after 40-50 years. The maximum fuel cladding temperature reaches about 175°C after approximately 25 years and decreases to less than 155°C by 100 years. Peak temperatures for the salt repositories as well as for repositories in the four other rock types are summarized in Table 4.

Temperatures resulting in the rock above the various reference repositories will also be available in the Reference Repository Conditions IWG reports. The expected temperature rise at the earth's surface was calculated as well and was always less than 0.1°C.

b. Fluid Environment. For the salt repositories, the fluid environment was calculated for normal operating conditions only, i.e., the only fluid assumed to contact the waste was that

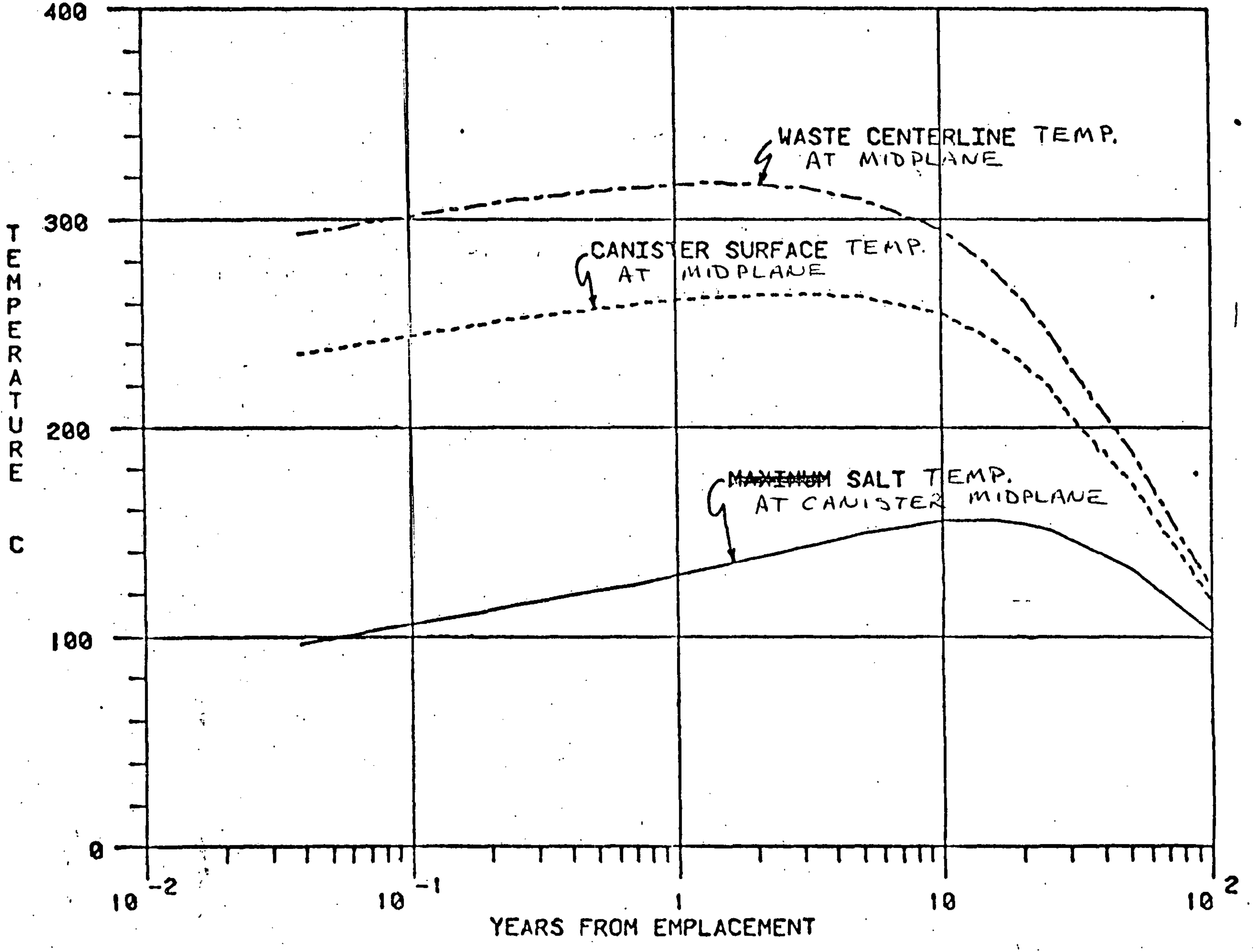

Figure 1. SALT TEMPERATURE HISTORIES FOR CHLW 25 w/m^2 (100 kW/acre)

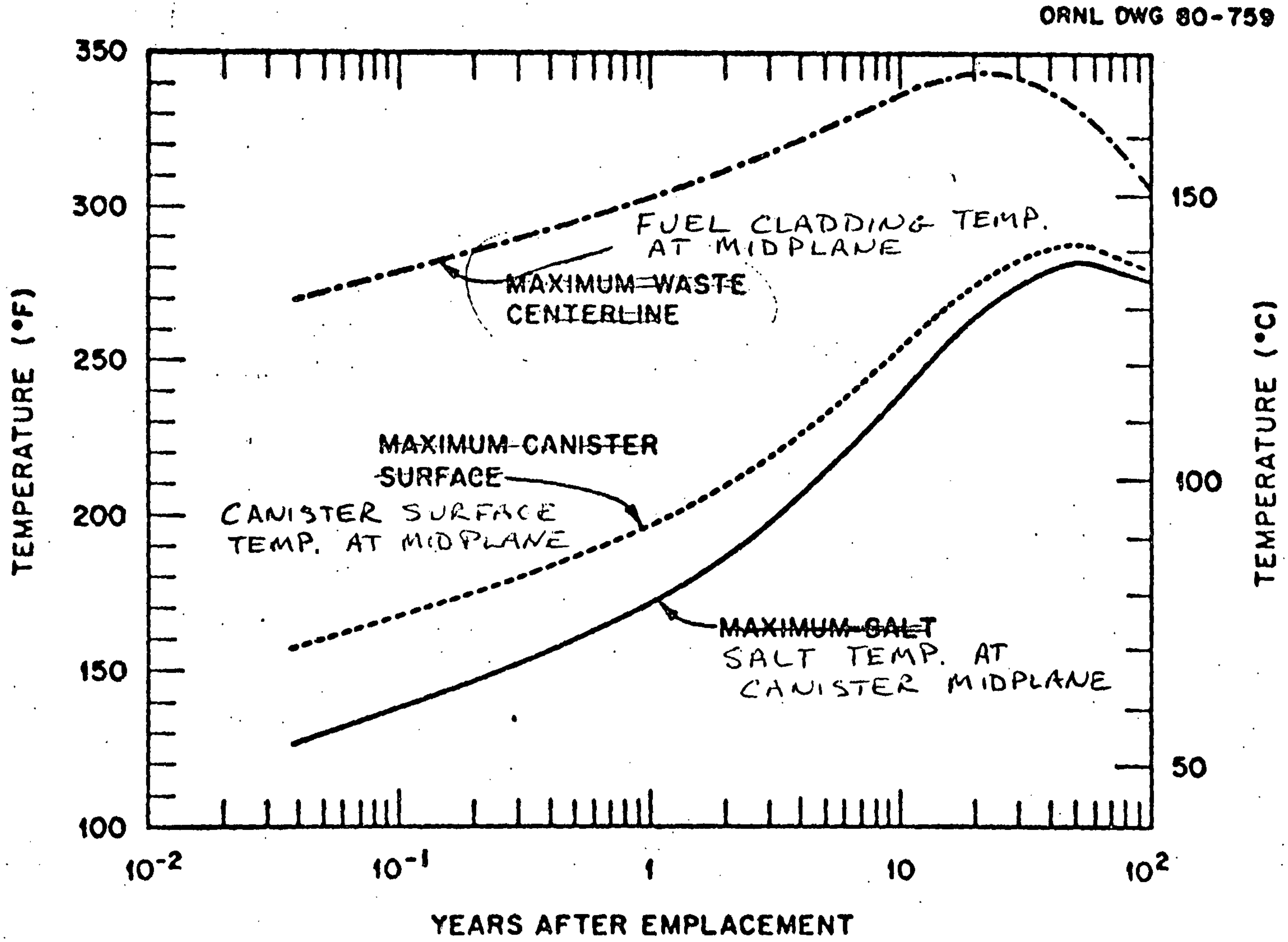

Figure 2. SALT TEMPERATURE HISTORIES FOR SF 25 w/m^2 (100 kW/acre)

TABLE 4. Reference Peak Near-Field Temperatures (°C)[a]

Host Rock	Location	SF	CHLW	DHLW
Salt	Host Rock	140	160	
	Canister Wall	145	260	
	Waste[b]	175	320	
Basalt	Host Rock	< 200[c]	---	---
	Canister Wall		---	---
	Waste[b]	< 300[c]	---	---
Tuff	Host Rock	190	215	---
	Canister Wall	200	235	---
	Waste[b]	220	275	---
Granite	Host Rock	150	165	105
	Canister Wall	170	205	115
	Waste[b]	190	225	120
Shale	Host Rock	125	140	125
	Canister Wall	140	210	135
	Waste[b]	165	235	140

(a) Assumes initial formation temperature of 34°C for salt, 57°C for basalt, 35°C for tuff, 20°C for granite, and 38°C for shale.

(b) Maximum centerline temperature for CHLW and DHLW; maximum cladding temperature for SF.

(c) Results for BWIP 3 PWR elements per canister waste package configuration.

resulting from migration of brine inclusions in the host rock.* The volume of water migrating to each emplacement hole was calculated using the predicted thermal gradients, an equation developed by Jenks [5] which relates the velocity of the brine inclusion to the temperature and temperature gradients, and the MIGRAIN code[2] which solves the equation for mass continuity numerically. The expected in-flow of brine per hole is about 8-9 liters for CHLW and 3-4 liters for SF in 1000 years. The reference composition of the accumulated brine is given in Table 5. It is worth noting that the total in-flow would only fill a small fraction of the emplacement hole if it were all to accumulate.

The situation for the repositories in hard rock (basalt, tuff, granite, and shale) is quite different. After closure, one would expect any such repository located below the water table to slowly fill with water. The rate of filling will depend on hydrologic conditions and heat output from the wastes. The ultimate composition of the water interacting with the waste packages depends on a variety of factors including rock and engineering materials compositions, radiation field, initial groundwater composition, temperature, pressure, and water replenishment rate. For the interim, the RRC-IWG has used available literature to identify representative compositions for the intruding groundwaters and established a set of reference compositions (Table 5). Insufficient data exist to specify reference compositions for groundwaters equilibrated with host rocks and engineering materials at high temperatures and pressures in a radiation environment.

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*The average initial concentration of brine inclusions was taken to be 0.5% by volume. This figure is typical of bedded salt, but it is a factor of 2-10 too high for dome salt and is, therefore, conservative.

TABLE 5. Reference Compositions for Intruding Waters

Constituent	Salt Brine A[a]	Salt Brine B[b]	Basalt[c]	Tuff[d]	Granite[e]	Shale[f]
		(mg/l)				
Lithium	20	---	---	0.04	---	
Sodium	42,000	115,000	250	46	125	
Potassium	30,000	15	1.9	6.6	0.4	
Rubidium	20	1	---	---	---	
Cesium	1	1	---	---	---	
Magnesium	35,000	10	0.04	2.4	0.5	
Calcium	600	900	1.3	14	59.	
Strontium	5	15	---	0.10	---	
Barium	---	---	---	0.2	---	
Iron	2[g]	2[g]	---	0.0	0.02	
Aluminum	---	---	---	0.03	---	
Silica	---	---	---	57	5.	
Fluoride	---	---	37	2.0	3.7	
Chloride	190,000	175,000	148	7.6	283	
Bromide	400	400	---	---	---	
Iodide	10	10	---	---	---	
Carbonate	---	---	25	0.0	3.	
Bicarbonate	700	10	21	124	10.	
Sulfate	3,500	3,500	108	25	19.	
Nitrate	---	---	---	5.6	---	
Borate	1,200	10	---	---	---	
Phosphate	---	---	---	0.12	---	
pH	6.5	6.5	9.7	7.1	9.	
Eh (volts)	mildly oxidizing	mildly oxidizing	-0.50	mildly reducing	+0.17	

(a) Brine A is based on analyses of brine inclusions in the McNutt potash zone in the Salado formation near Los Medanos, New Mexico.[6]

(b) Brine B results from dissolving a core sample from the Salado formation at the WIPP site in local ground water.[6] This latter brine represents that formed by a hypothetical mine flooding accident and would be the case if water flow were sufficiently slow to achieve saturation.

(c) Based on analyses of water from holes drilled in the basalts of the Hanford Reservation by the BWIP project [7].

(d) Based on reported analyses of water from well J-13 in the southwest corner of the Nevada Test Site.[8,9]

(e) The RRC-IWG experienced considerable difficulty in selecting a reference groundwater composition for granite. That reported for the Stripa Granite [10] was selected.

(f) The RRC-IWG has not yet selected a reference groundwater composition for shale.

(g) Iron as Fe^{+3}.

c. Pressure Environment. For salt a model was developed to predict pressure in the emplacement hole as a function of time based on the volume of the hole, its temperature, the volume of air in the hole, and the brine inflow rate through brine migration. Estimates of the pressure in the hole were made for two limiting cases.[2,3] In the first case, it was assumed that the hole was perfectly sealed. In the second, it was assumed that the hole was poorly sealed so that the pressure in the hole was essentially equal to that in the room.

In the first case, pressure peaks at about 3.2 MPa at 10 years for CHLW and 0.45 MPa at 50 years for SF. For CHLW pressure quickly subsides, decreasing to about 0.3 MPa at 100 years. For SF pressure decreases at a slower rate, reaching 0.4 MPa at 100 years. In the second, more probable, case, pressures remain near atmospheric (0.1 MPa) for the entire 100-year-period.

For hard rock, one may obtain the maximum possible vapor pressure in the emplacement hole during the operating phase of the repository by assuming the hole is perfectly sealed and calculating the saturation pressure corresponding to the maximum temperature of any surface exposed to the vapor. Clearly this is an overprediction in that the pressure in the hole is more likely determined by the minimum temperature of any surface exposed to the vapor. Further, it is not likely that any hole would be perfectly sealed, and all of them certainly would not be. If a hole is not well sealed, pressure will not rise significantly in it until after backfilling and sealing of the particular room in which it is located. In this case, pressure would remain essentially atmospheric until flooding of the underground excavations began.

Pressure would then rise at some, as yet, unknown rate until the local hydrostatic pressure was reached. At that point, pressure would remain constant. These limits are illustrated for the case of tuff[11] in Figures 3 and 4, where it is assumed that mine pumping ceases at 50 years and that the mine floods "instantaneously."

d. Nuclear Radiation Environment. Radiation dose rates and maximum integrated dose have been calculated for the several rock types for the reference SF and CHLW waste packages. For the case of salt, the maximum dose, which occurs at the inner edge of the crushed salt backfill, is roughly a factor of 15 greater for CHLW than for SF. At 10^4 years, the maximum doses are $\sim 1.5 \times 10^{10}$ rads for CHLW and $\sim 9.5 \times 10^8$ rads for SF.

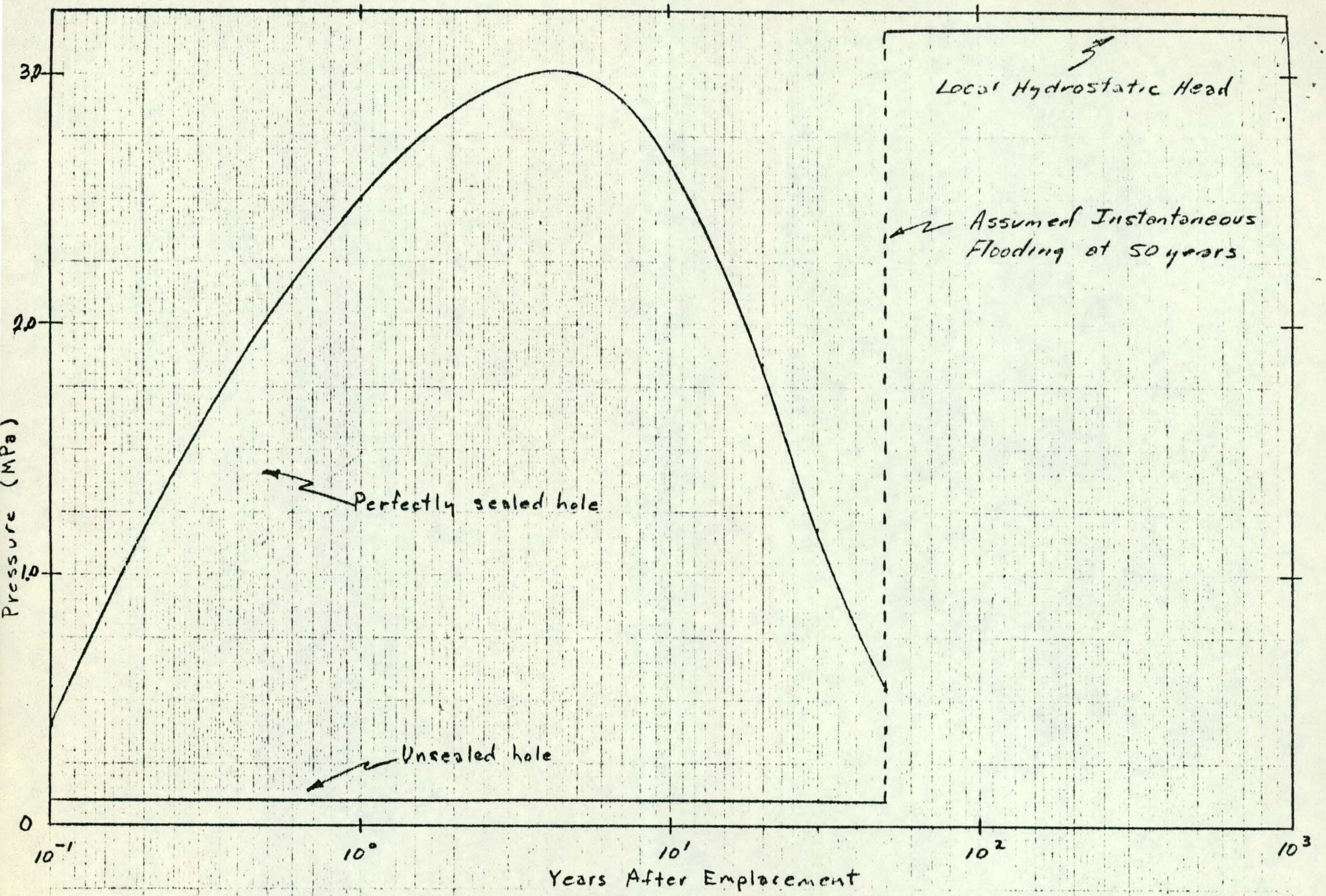

Figure 3. Limiting Vapor Pressures in Annulus between Canister and Emplacement Hole Wall for CHLW at 25 W/m² (100 kW/acre). Initial temperature was assumed to be 35 °C.

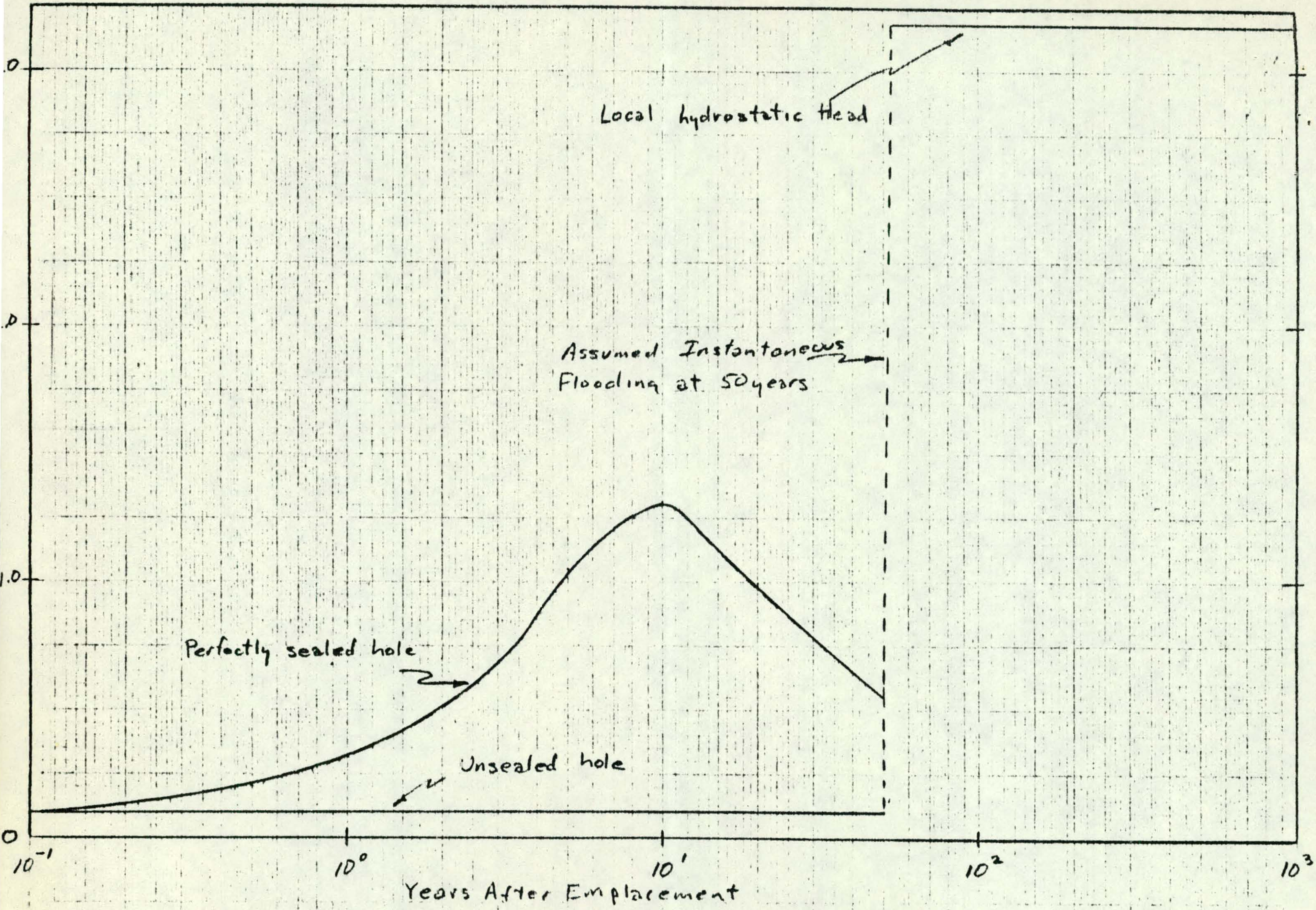

Figure 4. Limiting Vapor Pressures in Annulus between Canister and Emplacement Hole Wall for SF at 25 W/m^2 (100 kW/acre). Initial temperature was assumed to be 35°C.

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