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MONITORING SYSTEM SPECIFICATIONS:

MASTER

RETRIEVAL OF SURF FROM
A SALT REPOSITORY

PREPARED FOR:

WASTE MANAGEMENT PROGRAM
LAWRENCE LIVERMORE LABORATORY

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SOFTWARE DEVELOPMENT

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<p>The Supreme Court ruled in favor of the government by an 8-1 decision. The United States government had the authority through the use of the Commerce Clause to regulate interstate commerce. The Court ruled that the government had the authority to regulate interstate commerce. The Court ruled that the government had the authority to regulate interstate commerce.</p>	<p>Supremacy Clause - mainly federal government, but also states and local governments. It is a principle of federalism. It is a principle of federalism. It is a principle of federalism.</p>
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1.0 Introduction

An objective of the waste management program is to identify engineering design measures, performance constraints, and administrative controls which would mitigate the consequences of radionuclide release from the waste package. The Lawrence Livermore Laboratory (LLL) and its subcontractors are preparing a data base and methodologies which would enable the Nuclear Regulatory Commission (NRC) to formulate appropriate regulations and to evaluate license applications for commercial nuclear waste handling and disposal.

LLL assigned EA&T Company Inc. (dba Engineering Analysis and Test Company) the task of developing specifications for a reference monitoring system determined by repository environmental conditions, retrieval operations, and federal regulatory criteria. The monitoring system was to be capable of measuring (1) package position and orientation, (2) vault deformation, (3) brine accumulation, (4) spent fuel dissolution, (5) temperature (6) health physics nuclear radiation, and (7) package condition at enough points and with sufficient accuracy to provide probabilistic data input to a general risk assessment model.

In this report, the results of the investigations performed to establish preliminary monitoring system specifications are summarized. These specifications have been developed based on a preliminary conceptual design of a salt repository established by LLL and its subcontractors, ^(1,2,3) and by work performed by EA&T Company Inc. on identifying potential monitoring instrumentation which was presented in an earlier submittal.⁽⁴⁾

2.0 Summary, Conclusions and Recommendations

The monitoring system specified in this report is capable of measuring (1) package position and orientation, (2) vault deformation, (3) brine accumulation, (4) spent fuel dissolution, (5) temperature, (6) nuclear radiation and (7) package condition with sufficient accuracy to provide data input to a general risk assessment model. In order to define a monitoring system which can provide probabilistic data on radiological risk to operating personnel and the general public for a salt mine repository, the following information is required:

- A complete design of the salt SURF repository including inventory, density and waste package design details.
- Probabilistic failure rate data on containment integrity of the SURF waste package.
- Probabilistic failure rate data on the monitoring system components (i.e. monitoring procedure, instrumentation, data acquisition, data processing and data interpretation).

It is recommended that this work be continued to develop a detailed monitoring system design, as built-drawings, materials specifications, and operation procedures for data acquisition, processing and interpretation. This monitoring system design should be based on the attached specifications.

Then using guidelines found in IEEE Standard 500-1977 entitled "IEEE-Guide to the Collection and Presentation of Electrical, Electronic, and Sensing Component Reliability Data for Nuclear Power Plants", fault tree analyses yielding probabilistic data on radiological risk to operating personnel and the general public should be performed.

3.0 Repository Environmental Conditions

The repository environmental conditions are determined by the spent unprocessed fuel (SURF) waste package design, the repository architectural and geologic design, the salt chemical and structural description, repository ventilation system design, and those other features that could influence the occurrence of or consequence of events which represent risk to the health and safety of occupational workers or the general public.

3.1 SURF Waste Package

For SURF wastes in a salt repository, the LLL baseline design (1,2,3) of the retrievable SURF waste package is based on the following.

The depth of the emplacement hole is 27 feet with the canister buried 10 feet below the vault floor. The SURF canister is 16 feet long and is made from 12 inch diameter schedule 60 pipe with a wall thickness of 0.221 in (0.561 cm). This canister may or may not be enclosed within a sleeve of mild steel with a concrete plug extending 10 feet below vault floor grade.

The emplacement room is 18 feet wide and 25 feet high with an unspecified canister center-to-center spacing.

3.2 SURF Canister Contents

The SURF canister would typically contain a single fuel bundle along with the associated fuel cladding (typically zircaloy) and other metallic hardware (e.g. Inconel). The fuel would be in its metallic oxide form with the majority of the fission products entrapped within the ceramic material.

The spent fuel rods would contain varying quantities of volatile and semi-volatile fission products available for release. Ruthenium (Ru-106) and its daughter product rhodium (Rh-106) are termed semi-volatile because at elevated temperatures in the presence of air, ruthenium forms a tetraoxide (RuO_4), which has a vapor pressure that approaches one atmosphere. From a contamination control perspective, volatile fission products will readily be released from perforated canisters while the nonvolatile fission products will tend to remain in place. The relative activity of these volatile fission products is indicated in Table 1.

TABLE 1

ESTIMATED ACTIVITIES OF RADIONUCLIDES IN WASTES^f (Ci/MTHM)^g

Principal radionuclides	Half-life	SURF PWR ^a	Cycle BWR ^b	Cladding Wastes	
Volatile:					
H-3	12.3y	3.07E+2	2.54E+2		0
Kr-85	10.70y	4.90E+2	3.95E+3		0
C-14	5730y	1.08E-1	1.31E-5		0
Semi-Volatile					
Ru-106	1y	5.57E+2	4.27E+2	8.61E	0
Rh-106 ^d	30s	5.57E+2	4.27E+2	8.61E	0
Uranium:					
U-232	72y	1.94E-2	1.43E-2	8.59E-	6
U-233	1.6E + 5y	6.77E-5	5.32E-5	2.98E-	8
U-234	2.5E + 5y	1.04E 0	8.28E-1	5.06E-	4
U-235	7.1E + 8y	1.72E-2	1.43E-2	8.62E-	6
U-236	2.4E + 7y	2.60E-1	2.00E-1	1.30E-	4
U-237	6.7d	1.90E 0	1.64E 0	1.20E-	3
U-238	4.5E +9y	3.14E-1	3.17E-1	1.57E-	4
Plutonium:					
Pu-238	89y	2.21E+3	1.91E+3	1.15E	0
Pu-239	2.4E + 4y	3.31E+2	3.05E+2	1.65E-	1
Pu-240	6.6E + 3y	4.88E+2	4.67E+2	2.44E-	1
Pu-241	13y	7.89E+4	6.83E+4	5.00E+	1
Pu-242	3.9E + 5y	1.73E 0	1.42E 0	8.65E-	4
Particulates					
Sr-90	28Y	6.01E+4	4.89E+4	3.40E+	1
Y-90 ^d	64.8h	6.01E+4	4.89E+4	3.40E+	1
Tc-99	2.1E +5y	1.44E+1	1.21E+1		
Sb-125	2.7y	7.99E+2	6.39E+2	1.51E+	1
Te-125m ^d	58d	1.95E+2	1.56E+2	6.01E	0
I-129	1.6E + 7y	3.39E-2	2.87E-2	1.70E-	5
Cs-134	2.1y	9.16E+3	6.61E+3	2.46E+	1
Cs-137	30y	8.65E+4	7.17E+4	4.85E+	1
Ba-137m ^d	2.6m	8.19E+4	6.78E+4	4.59E+	1

TABLE 1 (Cont)

ESTIMATED ACTIVITIES OF RADIONUCLIDES IN WASTES^f (Ci/MTHM)^g

Principal radionuclides	Half-life	SURF PWR ^a	Cycle BWR ^b	Cladding Wastes
Particulates: (Cont)				
Ce-144	285d	1.47E+2	1.03E+2	6.28E 0
Pr-144d	17.3m	1.47E+2	1.03E+2	6.28E 0
Pm-147	2.6y	7.30E+3	6.35E+3	1.37E+1
Sm-151	90y	1.04E+3	9.06E+2	5.42E-1
Eu-154	16y	5.67E+3	4.39E+3	4.24E 0
Eu-155	1.8y	6.38E+2	5.08E+2	6.57E-1
Am-241	458y	1.75E+3	1.57E+3	5.25E-1
Am-242m	152y	6.96E 0	1.14E+1	5.63E-3
Am-243	7650y	1.72E+1	1.36E+1	8.58E-3
Np-239d	2.35d	1.72E+1	1.36E+1	8.58E-3
Cm-242	163d	5.72E 0	9.36E 0	8.61E-3
Cm-243	32y	2.35E 0	1.66E 0	1.31E-3
Cm-244	18.1y	1.35E+3	1.05E+3	8.15E-1

- a. PWR fuel irradiated 33,000 MWD/MTHM at 30 MW/MTHM, 10 year decay time. Chosen for maximum source strengths.
- b. BWR fuel irradiated 27,500 MWD/MTHM at 20.72 MW/MTHM, 10 year decay time.
- c. Combination of PWR-UO₂ and mixed oxide (MOX) fuels such that MOX fuel comprises 25 wt% of the total. The MOX fuel is 5% plutonium(fissile + non-fissile).
- d. Short-lived daughter product.
- e. Applies to both recycled cases. Only contaminants on cladding surfaces are shown. 5 year decay time.
- f. Y/OWI/TM-36/2-Part 1.
- g. MTHM = metric ton heavy metal.

3.3 Ventilation

Ventilation criteria for the repository have been suggested to provide for airflow that would comply with existing requirements of the U.S. Bureau of Mines, Mining Enforcement and Safety Administration (MESA), and state regulations and include: ⁽⁵⁾

- Minimum of 200 cubic feet per minute (cfm) of fresh air for each man underground.
- Minimum of 125 cfm per brake horsepower of diesel-powered equipment.
- Minimum of 50 cfm per square foot of headings (or 50 linear feet per minute of air velocities in entries).
- Minimum of 40,000 cfm of fresh air per mining machine.

Supply air entering the mine through the downcast shaft would be divided into the main corridors. The main portion of the supply air would be distributed to the working areas of the mining operations and to the rooms where SURF emplacement is in progress. Part of the supply air would be used for ventilating the underground mine equipment maintenance area for dust control at storage bin sites. Proper distribution of the ventilation air would be accomplished through the use of dampers and auxiliary fans with ventilation pipes at the working faces.

3.4 Temperature

Maximum allowable SURF canister temperature during retrievable and long term storage has been specified as 200°C (392°F).⁽⁶⁾ Maximum allowable vault temperature for personnel occupancy is limited by OSHA to less than 37.8°C (100°F).⁽⁷⁾ Maximum temperatures of retrieval equipment systems have yet to be established.

4.0 Retrieval Operation

The primary areas of concern in the event of SURF retrievability are that the storage room openings allow for canister retrieval and that the canisters themselves remain intact. In this work it is assumed that the SURF is to be removed from the repository 25 years after its emplacement.

Retrieval of the SURF canisters 25 years after emplacement involves a complex series of material handling operations, many of which must be performed remotely due to the hazards of direct radiation exposure and possible radionuclide contamination.

The potentially large number of canisters to be retrieved (i.e. on the order of 100,000) requires that the retrieval operation be performed in a timely and efficient manner.

For the purpose of investigating preliminary monitoring system specifications, the following retrieval scenario was⁽³⁾ formulated. In this scenario as presented, the assumed operations which verify retrieval equipment performance are assumed to be performed by the repository retrieval personnel and are not included in the repository monitoring function. However, those environmental parameters which could potentially impact radiological risk to the general public and are not under the control of retrieval personnel are considered within the monitoring function and are italicized.

4.1.0 Retrieval Preparation

4.1.1 Determine Radiation & Contamination Levels

4.1.2 Determine Degree of Vault Deformation

4.1.3 Remine Room to Orignal Contours

4.1.4 Determine Package Position & Orientation (PP&O)

4.1.5 Grade Floor to Expose The Top of Concrete Plug and Level Perpendicular to Longitudinal Axis of Sleeve for Floor Flange.

4.1.6 Place, Bolt & Grout Floor Flange in Place

4.1.7 Test & Actuate Floor Flange Gate (FFG)

4.1.8 Position Plug Removal Machine (PRM)

4.1.9 Open PRM Appartus Gate

4.1.10 Open FFG

4.1.11 Lift Canister Emplacement Plug (CEP) Into PRM Radiation Shielded Housing

4.1.12 Determine Package Condition

(i) Contamination Level,

(ii) Radiation Level,

(iii) Sleeve Condition,

(iv) Annulus Condition, and

(v) Canister Condition

4.1.13 Determine Retrieval Mode

(i) Normal Reverse Emplacement,

(ii) Abnormal Ram Retrieval,

(iii) Core Drill Sleeve,

(iv) Excavate, or

(v) Abandon

- 4.1.14 Close PRM gate
- 4.1.15 Close FFG
- 4.1.16 Remove PRM
- 4.2.0 Normal Reverse Emplacement
 - 4.2.1 Position Canister Extraction/Transporter (CET)
 - 4.2.2 Open CET Gate
 - 4.2.3 Orient Lifting Device
 - 4.2.4 Verify Alignment of Canister PP&O & Lifting Device
 - 4.2.5 Lower Lifting Device
 - 4.2.6 Engage Lifting Device with Canister
 - 4.2.7 Raise Canister into CET
 - 4.2.8 Close CET Gate
 - 4.2.9 Remove CET
- 4.3.0 Core Drill
 - 4.3.1 Orient Core Drill
 - 4.3.2 Verify Alignment of Sleeve & Drill
 - 4.3.3 Core Drill
 - (i) Observe drill bit temperature
 - (ii) Observe swarth removal
 - (iii) Observe alignment of core barrel & package
 - 4.3.4 Verify sleeve enclosure in core barrel at midpoint
 - 4.3.5 Cut & Remove upper sleeve
 - 4.3.6 Bore with core drill to bottom of sleeve
 - (i) Observe drill bit temperature,
 - (ii) Observe swarth removal, and
 - (iii) Observe alignment of core barrel & package

- 4.3.7 Under-cut sleeve with lifting fingers
- 4.3.8 Remove core drill and core containing sleeve into transporter
- 4.3.9 Close CET gate
- 4.3.10 Close FF gate
- 4.3.11 Remove CET
- 4.4.0 Abnormal Ram Retrieval
 - 4.4.1 Orient extraction ram
 - 4.4.2 Verify alignment of canister & ram
 - 4.4.3 Lower ram
 - 4.4.4 Verify canister enclosure in ram
 - 4.4.5 Engage the ram latches
 - 4.4.6 Raise canister ram
 - 4.4.7 Close CET gate
 - 4.4.8 Close FF gate
- 4.5.0 Excavate
 - 4.5.1 Excavate to base of sleeve
 - 4.5.2 Cut sleeve above canister
 - 4.5.3 Emplace sleeve sections & canister in CET
 - 4.5.4 Close CET gate
 - 4.5.5 Remove CET

5.0 Monitoring System Criteria

It is reasonable to assume that the same level of regard for public health and safety and environmental protection will exist in the licensing on interim or ultimate waste disposal facilities as presently exist for the front end of the nuclear fuel cycle. For this reason, the preliminary specifications contained in this report have been established based on meeting criteria extracted from Federal Codes which were drafted for licensing of existing nuclear fuel cycle facilities.

Licensing considerations dictate that all existing federal codes be complied with. Existing licensing criteria are found in the following:

- Title 10, Chapter 1, Code of Federal Regulations-
Energy.⁽⁸⁾
- Title 30, Chapter 1, Code of Federal Regulations-
Mineral Resources-Mine Safety & Health Administration.⁽⁹⁾
- Title 40, Chapter 1, Code of Federal Regulations-
Protection of Environment-Environmental Protection
Agency.⁽¹⁰⁾
- Title 49, Chapter 1, Code of Federal Regulations-
Transportation of Hazardous Materials-Department of
Transportation.⁽¹¹⁾

6.0 Monitoring System Specifications

Preliminary monitoring system specifications are identified here based on repository environmental conditions, retrieval operations, and licensing criteria. As the repository environmental conditions and retrieval operations, and monitoring criteria become better defined, it is expected that these preliminary monitoring specifications will be refined and expanded.

Package position and orientation determination will be affected by such considerations as whether a sleeve will be employed or not; whether backfill material around the canister will be emplaced; the site specific characteristics of salt chemistry, moisture, the presence of interstitial clay or shale seams; etc. All of these factors will affect the transmission velocity and attenuation of electromagnetic and acoustic signals and will therefore impact the desired power and frequency of the signal.

Vault deformation will be affected by many of the factors which impact package position and orientation. In addition, repository temperature will have a major impact on salt creep leading to room closure. The degree of surface faulting and depth of damaged or weakened salt mine structure will be dependent on the mining technique employed. All of these factors will impact the number, depth of emplacement and required resolution of the mechanical deformation gages.

The most important factor on the resolution of water and brine migration by resistivity logging techniques will be the moisture content of the salt itself. However, salt chemistry and temperature will also impact resistivity values. The resistivity of the salt will determine the required power and spacing between current and potential electrodes.

Spent fuel dissolution determinations by nuclear activity logging will be largely affected by ventilation flow rates as the concentration of volatile fission products will vary inversely with the flow rate. The depth of canister placement, packing density, use of backfill material etc., will all effect the background countrate which will have a major impact on resolution and consequently the required wall thickness of the Geiger-Muller Tube.

Temperature will be determined by canister packing density, ventilation flow rates and site specific characteristics of the local geology of the salt mine repository.

Health physics nuclear radiation levels to be encountered in personnel occupied areas will be determined by package containment capability. However, the resolution to which such measurements must be made will be determined by federal criteria which historically has set the limits below the state-of-the-art of the instrumentation measurement capability.

For example, the maximum permissible concentration of mixed fission products in personnel occupied zones⁽¹²⁾ is less than 6×10^{-13} micro'curies per milliliter. This level is below the sensitivity of state-of-the-art field measurement instrumentation.

Package condition determination by remote ultrasonic testing will be largely impacted by package design details such as canister steel designation, wall thickness, finish surface texture, and physical handling characteristics. These factors will influence the final selection of frequency pulse duration and power level.

The following preliminary specifications are based on the information contained in the attached appendices.

SPECIFICATIONS
for
PACKAGE POSITION AND ORIENTATION*
by
ELECTROMAGNETIC PULSE REFLECTION

Frequency: 750 MHz	@ Wavelength: 16.5 cm
Power: 10. watt	@ Max. Range: 150 meters
Travel Time: 200 nsec	@ 10 meters
Pulse Length: 10 nsec	
Attenuation gain factor: 100 db	Absorption: 0.1 db/m
Antenna Beam Width $\pm 3^\circ$	Antenna Length: 1.0 meters Antenna Width: 8 to 30 cm
Resolution Band Width: 50 cm	@ 10 meters with an angle of incidence of 45°
Resolution Band Width: 2 cm	@ 10 meters with an angle of incidence of 90°

(1) *Assumes 0.08% moisture plus impurities symmetrically distributed about package.

(2) *Assumes geometric attenuation of $2\pi r^2$.

SPECIFICATIONS
for
PACKAGE POSITION AND ORIENTATION
by
ACOUSTIC PULSE REFLECTION

Frequency: 24 KHz	Wavelength: 9 cm
Power: 10 watt	Max. Range: 150 meters
Travel Time: 0.33 msec	@ 10 meters
Pulse Length: .01 msec	
Attenuation gain factor: 100 db	Absorption: 0.02 db/m
Resolution: 2 cm	@ 10 meters with an angle of incidence of 90^0

- (1) *Assumes burial in salt with .08% moisture plus impurities symmetrically distributed about package.
- (2) *Assumes geometric attenuation of $2\pi r^2$.

SPECIFICATIONS
for
VAULT DEFORMATION
by
MECHANICAL DEFORMATION GAGES

Room Closure: Pipe-type gage in both vertical
and lateral horizontal directions.

Resolution: 0.01 cm

SPECIFICATION
for
WATER AND BRINE MIGRATION
by
RESISTIVITY LOGGING

Power: 10 watts AC

Voltage: 10mV-20Vac

Current: 5-500mA AC

Attentation
gain factor: 50 db

Depth of Well: 40 feet

Measurements: 10 feet spacing

Spacing between current
& potential electrode:
64 inch

Radius of Current Penetration:
128 inch

Electrode: Stainless Steel

Resolution: ± 10%

@ 10^{-3} to 10^{-6} ohm-cm

SPECIFICATIONS
for
SPENT FUEL DISSOLUTION
by
NUCLEAR ACTIVITY LOGGING

Detector: Geiger-Muller Tube

Count Rate: 100 cpm/mr/hr

Active Volume: 5 cm³ Voltage: 2000 VDC

Range: 0-1 R/HR

Wall Thickness: 550 mg/cm²

Well Depth: 40 feet

Resolution: ± 5% F.S. for ¹³⁷Cs

SPECIFICATIONS
for
TEMPERATURE DETERMINATION
by
THERMOCOUPLE MEASUREMENTS

Type: K

Chemistry: 90% Ni, 10% Cr
for chromel

Range: 0 to 250°C

93% Ni, Al, Si, Mn
for Alumel

Potentiometer EMF:
0 to 10.15 millivolts

Resolution: $\pm 1^{\circ}\text{C}$

SPECIFICATIONS
for
HEALTH PHYSICS NUCLEAR RADIATION
by
AIR PARTICULATE MONITORING

Detector: Air Monitor-Particulate

Filter: 5 cm diameter, 0.3 μ m fixed filter

Flowrate: 10 to 100 liter per minute

Shielding: 4 π geometry equivalent of 5 cm lead

Range: 10 to 10^6 cpm

Resolution: 10 cpm per 10^{-6} mCi/ml

SPECIFICATIONS
for
PACKAGE CONDITION DETERMINATION
by
REMOTE ULTRASONIC TESTING

Frequency: ~10MHz Wavelength: ~.01 cm

Pulse duration: 0.1 nsec

Power: 0.1 watt

Resolution: .01 cm

APPENDIX 1

MONITORING
CANISTER LOCATION & ORIENTATION
by
ELECTROMAGNETIC PULSE REFLECTION

MONITORING CANISTER LOCATION AND ORIENTATION

BY

ELECTROMAGNETIC PULSE REFLECTION

1.0 Introduction

The use of electromagnetic (EM) pulse radar is under consideration for the determination of SURF canister location and orientation at a high level waste salt repository during retrieval operations. A limited amount of data exists on the transmission characteristics of EM waves in a salt medium. (13,14,15,25,26)

2.0 Summary and Conclusion

A summary of the results of investigations conducted to date includes the following:

- Attenuation of EM pulse signals in rock salt containing impurities and having an average moisture content of 0.08% is 6.9×10^{-2} db/m. The attenuation to a first order is frequency independent. As a result, neglecting geometrical attenuation, a signal traveling a distance of 20 meters and emitting at a power of 1.0 watt is received at a power of 0.73 watt.
- Attenuation of EM pulse signals in hot brine is quite pronounced. A signal of 1.0 watt traveling through 3 mm of brine at 100°C (212°F) would be reduced to 0.04 watt.
- Reflection of the EM signal occurs if it encounters an interface of a material of different dielectric constant. The principal interfaces within the salt repository which would cause a reflection are the canister, an

impurity layer (e.g. clay or granite seam), brine layer, and air.

- A frequency of 750 MHz would appear to have the required resolution (i.e. location within a few centimeters) with reasonable attenuation (i.e. less than one tenth of a decibel per meter).
- Travel times of on the order of 200 nsec for a 10 meter distance are expected. This compares favorably with electronic counting capabilities (i.e. less than 1.0 nsec resolution).

3.0 Description of Instrumentation

The electromagnetic pulse reflection instrumentation investigated for application consists of a signal transmitter, a transmitter/receiver antenna, signal conditioners, electronic clock and data display cathode ray tube. This instrumentation is comparable to a conventional radar pulse echo depth finder. Transmitted impulses traveling through the salt would be partially reflected at interfaces with media of differing dielectric properties. The velocity of the EM pulse wave in the salt may be determined by measuring the travel time and distance between two boreholes. Then the travel times of reflected pulses may be used to determine the depths of interfaces causing reflections.

4.0 EM Signal Transmission

Signal transmission is a function of frequency, moisture, temperature, brine concentration, impurities, concentration and density of salt. In dry rock salt at normal temperatures the exploration range can be up to 1000 feet.

The exploration range depends on the coefficient of absorption of EM waves. The absorption is a factor of dielectric constant, frequency, conductivity and magnetic permeability.

Let E_o be the electric field of the emitted wave and E_x be the field of the received wave, after a travel path x through the rock salt. Then (13)

$$E_x = E_x \underbrace{e^{-\alpha x}}_{\text{attenuation}} \underbrace{e^{i(\beta x - \omega t)}}_{\text{oscillation term}} \quad (1)$$

$$\text{with } \alpha = 12.863 \times 10^{-8} f \sqrt{E_r} \left[\sqrt{\tan^2 \delta + 1} - 1 \right]^{1/2} \text{ db/m} \quad (2)$$

f : frequency of EM wave (Hz)

E_r : relative dielectric constant; $E_r = \frac{E}{E_o}$

E_o : 8.85×10^{-12} (farads/m)

E : dielectric constant

$$\tan \delta = \frac{\sigma}{2\pi f E_o E_r} \quad (3)$$

σ : conductivity (mohs/m)

μ_r : magnetic susceptibility

$$\mu_r = 1 \quad \mu_r = \frac{\mu}{\mu_o}$$

if $\tan \delta \ll 1$ - poor conductor - then $(\sqrt{\tan^2 \delta + 1} - 1)^{1/2} \rightarrow \tan \delta$

if $\tan \delta \gg 1$ - good conductor - then $(\sqrt{\tan^2 \delta + 1} - 1)^{1/2} \rightarrow \tan \delta$

4.1 Conductivity in Salt

A literature search was conducted to find data on the conductivity and dielectric constants of salt impurities in salt, brine and moisture, steel and uranium dioxide. This data was then used to calculate the attenuation and depth of penetration of EM waves. From this data, interfaces that produce reflections were identified. Table 1.1 shows the variation of the electrical conductivity of salt with temperature.

Table 1.1 Conductivity σ (mohs/m)

Composition	Reference	$\sigma(20^{\circ}\text{C})$	$\sigma(100^{\circ}\text{C})$
Dry, pure salt	24 25	2.2×10^{-15} 10^{-13}	7.1×10^{-12}
Rock salt impurities + 0.08% moisture	24 25	10^{-4} 3.33×10^{-2}	
Pure saturated brine (26%)	24	25	67
Saline waters 20% saturated brine	25	20	
Sea water	13	4	
Soil waters	25	10^{-2}	
Surface waters	13 13	10^{-3} 10^{-4} to 3×10^{-2}	
Air	13	0	
Sylvite KCl Calcite CaCO_3 Anhydrite - Gypsum CaSO_4	25 25 25	10^{-11} to 10^{-12} 5×10^{-13} 10^{-9}	
Clays Wet Clays	25 25	1×10^{-2} 5×10^{-2}	

Table 1.1 continued

Composition	Reference	$\sigma(20^{\circ}\text{C})$	$\sigma(100^{\circ}\text{C})$
Uranium	29	0.24×10^5	1.0×10^5
	25	3.3×10^5	
Uranium dioxide	29	$(46.7, 61, 95, 114) \times 10^5$	80×10^5
	29	12.7×10^5	37×10^5
	29	8.3×10^5	
Iron	25	10^7	
Nickel	25	1.3×10^7	

4.2 Dielectric Constant, E_r

The dielectric constant, E_r , is calculated from the index of refraction, n , of salt. The index of refraction and the dielectric constant are related by:

$$E_r = n^2 \quad (\text{reference 14})$$

$$n = \frac{c}{V_m} \quad (\text{reference 13})$$

c = propagation velocity on free space (3×10^8 m/sec)

V_m = velocity in the medium

$$V_m = \frac{x}{t}$$

x = traveling distance

t = traveling time

Table 1.2 Dielectric Constants

Element	Reference	E_r (normal temperature)
Pure Crystalline Salt	26	5.9 Independent of frequency
	29	5.7 - 6.2
	25	6.12
Rock Salt	15	6
	25	5.6
Dome salt 1300 feet 700 feet	14	5.4 } deduced from transmissions
	14	5.3 }
	14	5.1 } deduced from reflections

Table 1.2 continued

Element	Reference	ϵ_r (normal temperature)
Sea Water	13	81
Water	13 25	81 80.36
Air	13	1
Clays-dry to moist	25	7 - 43
Calcite CaCO_3	25 & 29	7.8 - 8.5
Gypsum $\text{CaCO}_3 + \text{Water}$	25	5 - 11.5
Anhydrite CaSO_4	29	5.7 - 6.3
MgO	28	9.65
KCl	29	4.4 - 6.2
Porcelain	25 28	6.0 - 8.0 5.5
Titanium Dioxide	28	14 - 110
Ferrous Oxide	25	14.2

The relative difference in the value of the dielectric constants of two adjoining media determines if an EM wave is reflected or not. For rock salt the dielectric constant is approximately 5.5. Therefore EM waves traveling through salt would be reflected at interfaces with air, clay, water or iron oxide. However, interfaces with uranium dioxide calcite or gypsum might not produce reflections. The dielectric constants of various materials are listed in Table 1.2.

4.3 Magnetic Susceptibility, μ_r

The magnetic susceptibility of rock salt is very closely equal to one and therefore has a negligible effect on signal transmission.

$$\mu_r \text{ (rock salt)} \approx 1$$

$$\mu_r \text{ (anhydrite, gypsum)} = 1$$

$$\mu_r \text{ (clays)} = 1.00002$$

$$\mu_r \text{ (calcite)} = 0.999987$$

4.4 Mineralogic Data on Rock Salt

Rock consists of halite crystals having a diameter of 2 mm to 50 mm. Clay & anhydrite interlaminae (polyhalite) are situated from 0.25 to 3.0 inches apart in natural rock salt. These seams of impurities make up to 2% and 10% of the rock salt. The main impurities are: anhydrite, clay, polyhalite, sylvite and potash. The average natural moisture content of intact rock salt is 0.08%. Some mines show a large variation of that average value; for example, the New Mexico salt mines have a moisture content of 1.75%. (27)

4.5 Attenuation of EM Waves

From the previous collection of data, the attenuation of EM waves in rock salt is calculated. The following data in Table 1.3 gives an overview of the attenuation of EM waves in the different media.

Table 1.3 Attenuation of EM Waves

Element	σ (mohs/m)	f(MHz)	E_r	$\tan\delta$	α (db/m)	x(m)	$e^{-\alpha x}$	E_o	E_x
Dry Rock Salt	7.1×10^{-12} 2.2×10^{-15} to	750	5.1	3.3×10^{-11} 1.0×10^{-14} to	7.2×10^{-3} to 2.3×10^{-12}	100	0.999	1watt	0.99watt
Rock Salt + impurities + 0.08% moisture	10^{-4}	750 500 100	5.6	4.3×10^{-4} 6.4×10^{-4} 3.2×10^{-3}	6.9×10^{-2} independent of frequency	100 20 1000	2×10^{-1} 7.2×10^{-1} 1×10^{-7}	10watt 10watt 100KW	2watt 7.2watt 10m W
Pure satu- rated brine at 100°C	76	1000 750 500 100	81	16.9 22.5 33.8 169	4.6×10^3 4.0×10^3 3.3×10^3 1.5×10^3	1mm 3mm 10mm 15mm	3.4×10^{-1} 4×10^{-2} 2.3×10^{-5} 1.1×10^{-7}	10watt 10watt 1kwatt 100KW	3.4watt 0.4watt 23mwatt 11mwatt
Wet rock salt soil waters	10^{-2}	1000 500	81	1.9×10^{-2} 3.9×10^{-2}	16.36 16.35	1m 2m 4m	2.2×10^{-2} 4.9×10^{-5} 2.5×10^{-7}	10watt 10W 100KW	220mwatt 4.9mw 25mw
Air	0	1000	1	0	0	indep.	1	1watt	1watt
KCL	10^{-11} 10^{-12}	1000	6.2 4.4	2.9×10^{-11} 4.1×10^{-12}	9.2×10^{-3} 1.1×10^{-3}	100 100	0.9999 0.9999	1watt 1watt	0.99watt 0.99watt
Anhydrite	10^{-9}	1000	6.0	3×10^{-9}	9.5×10^{-7}	100	0.9999		
Clays dry- moist	10^{-2} 1	1000 1000	7 43	2.6×10^{-2} 4.2×10^{-1}	6.256 2.45×10^2	1 m 10mm 100mm	2.3×10^{-1} 5.7×10^{-1} 3.4×10^{-3}	10watt 10watt 10watt	2.3watt 5.7watt 34mw

NOTE: α in db/m must be divided by $10 \log_{10} e = 4.34$ to convert to 1/m units in Table 1.3.

4.6 Frequency of EM Signal

The frequency of the EM wave which makes up the pulse is a variable parameter in the instrumentation system.

The frequency chosen is based on the size of the reflecting object of interest. The smaller the object, the higher the frequency and the shorter the wavelength required.

Frequency is related to the velocity of transmission, V_m , and wavelength, λ , as follows:

$$f = \frac{V_m}{\lambda}$$

Where the velocity of propagation is related to the velocity of EM wave transmission in air, c , and the dielectric constant, E_r , of the medium as follows:

$$V_m = \frac{c}{\sqrt{E_r}}$$

For rock salt, the dielectric constant is approximately 5.5., therefore:

$$V_m = \frac{3 \times 10^8 \text{ m/sec}}{\sqrt{5.5}} \approx 1.3 \times 10^8 \text{ m/sec}$$

If the object of interest is a SURF canister with a 30.5 cm (1.0 ft) diameter and the desired resolution of location is on the order of 10 cm then:

$$30.5 \text{ cm} \geq \lambda \geq 10 \text{ cm}$$

therefore

$$\frac{3 \times 10^8 \text{ m/sec}}{.30 \text{ m}} \leq f \leq \frac{1.3 \times 10^8 \text{ m/sec}}{.10 \text{ m}}$$

$$433 \text{ MHz} \leq f \leq 1300 \text{ MHz}$$

A midrange value of 750 MHz would appear to theoretically provide the required object resolution while minimizing noise to the system as a result of reflections by smaller potential objects.

4.7 Signal Travel Times

The resolution of the instrumentation system in locating a buried SURF canister is dependent on the accuracy with which the electronic clock can determine the travel time between pulse transmission and receipt of the reflected signal. If a 750 MHz signal is transmitted and reflected through a distance 30.5 m (100 ft), the travel time is then

$$t = \frac{x}{v_m} = \frac{30.5 \text{ m}}{1.3 \times 10^8 \text{ m/sec}}$$

$$t = 200 \text{ n sec}$$

It would appear that this time domain is within the state of the art of electronic measurement.

APPENDIX 2

MONITORING
CANISTER POSITION AND ORIENTATION

by
ACOUSTIC PULSE REFLECTION

MONITORING CANISTER POSITION AND ORIENTATION

by

ACOUSTIC PULSE REFLECTION

1.0 Introduction

The determination of SURF canister package position and orientation within a salt repository utilizing acoustic pulse reflection technologies during retrieval operations is under investigation as a potential monitoring activity. Acoustic reflection measurements have recently been used in salt mining operations to locate buried objects such as drill bits, pipes, shale seams, ⁽¹⁵⁾ etc. The use of acoustic pulse reflection techniques to locate a SURF canister buried in a salt mine is presented here.

2.0 Summary and Conclusions

Acoustic reflection technologies would appear to be an appropriate means of determining SURF canister position and orientation in a salt repository during retrieval operations. The following summarizes the information generated to date in this effort.

- Attenuation of acoustic pulse signals in rock salt containing impurities and having an average moisture content of 0.08% is frequency dependent and approximately equal to $\alpha = 10^{-5} f^* 0.9 \text{ db/cm}^{(16)}$ (e.g. $\alpha \approx 1.7 \times 10^{-2} \text{ db/m}$ @ 24 KHz and $\alpha = 6.3 \times 10^{-2} \text{ db/m}$ @ 100 KHz).
- Attenuation of acoustic pulse signals in hot brine is negligible, being less than 10^{-4} m^{-1} for all brine compositions of interest.
- Reflections at interfaces of different media are determined by the differences in density, Young's modulus and Poisson's ratio. Acoustic pulse signals traveling through salt would tend to be reflected from air, steel, and uranium dioxide and to a lesser extent, from moist salt.
- A frequency of 24 to 100 KHz with corresponding wavelengths of 9 cm to 2.5 cm respectively for a velocity of $3 \times 10^3 \text{ m/sec}$ would appear to provide adequate resolution with reasonable attenuation.

* f = Kilohertz

3.0 Description of Instrumentation

The instrumentation investigated consists of an acoustic signal generator and horn-transducer receiver, signal conditioners, an electronic clock and various data display schemes. As with the EM system, the insitu velocities would be determined from local borehole measurements. Then the travel times of reflected impulses would be used to determine the depths of interfaces causing reflections. Table 2.1 lists the material properties which determine acoustic signal velocity.

TABLE 2.1 Acoustic Signal Velocity

	Reference	density ρ kg/m ³	moisture m %	porosity ϕ %	Young's modulus E N/m ²	Poisson's ratio σ	Lame's Constant N/m		Velocity V_P km/sec
							μ	λ	
Generic salt average values	8	2082	0.08	3.3	1.27×10^{10}	.34	0.47×10^{10}	1.01×10^{10}	3.06
Intact salt average	8	2130	0.08	0.5	1.12×10^{10}	.35	$.41 \times 10^{10}$	$.97 \times 10^{10}$	2.55
New Mexico	8	2114.5	1.75	3.0	0.14×10^{10} 1.4×10^{10}	0.33	$.05 \times 10^{10}$ $.5 \times 10^{10}$	0.10×10^{10} 1.02×10^{10}	.97 3.09
Water	9,6	1000	—	—	0	0.50	0	0.19	1.4
Brine 26% salt in solution	6	1207- 1149	—	—	0	.50	0	0.29×10^{10}	1.56- 1.66
Uranium Dioxide	9 10 11	10960- 10% =9.860	—	—	2.23×10^{11} to 1.69×10^{11}	0.316- 0.306	0.874×10^{11}	1.50×10^{11}	5.44
Steel	9	7830-	—	—	2×10^{12}	—	—	—	5.85

4.2 Attenuation in Salt

The loss of energy by absorption of an acoustic wave is exponential with distance and is expressed as:

$$I = I_0 e^{-\alpha x} \quad \text{where} \quad \alpha = \text{Attenuation coefficient}$$

I = Intensity at reception

I_0 = Intensity at emission

x = Twice the distance to the reflecting surface

The attenuation coefficient is frequency dependent.

In rock salt the attenuation has been given (16) as:

$$\alpha = 10^{-5} f^{0.9} \text{ db/cm; where}$$

$$1 < f < 100 \text{ KHz}$$

For acoustic signal frequency of 100 KHz,

$$\begin{aligned} \alpha &= 10^{-5} (100)^{0.9} \times 10^2 \text{ db/m} \\ &= 6.31 \times 10^{-2} \text{ db/m} \end{aligned}$$

or

$$\begin{aligned} \alpha &= 6.31 \times 10^{-2} \text{ db/m} \times (4.3 \text{ db})^{-1} \\ &= 1.47 \times 10^{-2} \text{ m}^{-1} \end{aligned}$$

4.3 Attenuation in Liquids

Attenuation of acoustic signals by absorption in the passage through a liquid is given as (17);

$$\alpha = \alpha_{\text{viscous}} + \alpha_{\text{thermal}} \\ = \frac{2\pi^2}{P v^3} \left[\frac{4}{3} n + \left(\frac{\gamma - 1}{\gamma} \right) \frac{K}{C_v} \right] f^2$$

Where P = density

v = velocity of sound

γ = ratio of principal specific heats

n = coefficient of shear viscosity

K = coefficient of thermal conduction

C_v = specific heat at constant volume

f = frequency

The above parameters are all temperature dependent.

In the temperature range $20^\circ\text{C} < T < 100^\circ\text{C}$, the coefficient of absorption was given as 2.5×10^{-4} 1/m to 6×10^{-10} 1/m, respectively (17,18). It is apparent from these values that the attenuation by absorption in water or brine is negligible relative to that in salt.

APPENDIX 3
MONITORING VAULT DEFORMATION
by
MECHANICAL DEFORMATION GAGES

1.0 Introduction

The salt repository is expected to undergo deformation due to stresses present as a result of gravitational forces on the surrounding rock masses and due to thermal creep and expansivity. Monitoring of vault deformation has been identified as an activity which would have health and safety risk implications during any potential retrieval operation.

Vault deformation impacts health and safety in a variety of ways. During retrieval operations, the ability to predict eminent failure of vault mine structural integrity could substantially reduce the risk of package failure during handling. The ability to retrieve canisters by the reverse emplacement mode (see section 4.2) is largely determined by the degree of vault deformation. Normal reverse emplacement would appear to offer among the alternatives presented a lower risk.

2.0 Summary and Conclusions

The following represents the results of investigations conducted to date on vault deformation to establish monitoring system specifications:

- Vault deformation during retrieval may be monitored using conventional instrumentation systems and practices.
- Displacements of on the order of 1.0 meter are expected due to the combined affects of gravitational forces and thermal creep.
- Voids in walls and ceiling due to seam separation may be located using either EM or acoustic reflection techniques.

3.0 Description of Instrumentation

Instrumentation to monitor vault deformation may be classified in two basic groups, those to measure the degree and rate of room closure and those to indicate internal voids due to separation at salt seam interfaces. In the first instance, mechanical deformation gauges are suggested while in the latter, acoustic and electromagnetic, (EM) reflection systems are indicated.

Mechanical deformation gauges consist of pipes buried in pairs in the adjacent walls of the vault. The separation and alignment of the pipes then indicate vault deformation locally.

Electromagnetic and acoustic reflection techniques are discussed in appendices 1 and 2 respectively. As discussed, the differences in the material physical properties of interfaces results in reflections and the differences in velocity of transmission is an indication of differences in density. Therefore, pulse reflection techniques could be used to detect internal voids due to separation at salt seam interfaces.

4.0 Vault Deformation

Previous investigations have indicated⁽⁴⁾ that at a depth of approximately 600 meters (1800 ft) the stress level due to gravitational forces alone is roughly 0.27 Kbar (4Ksi). With salt temperatures increased due to decay heat released from the SURF, estimates of thermal creep as high as a total movement of 120 cm (4 ft) expansion on the floor and 60 cm (2 ft) deformation on the walls and sag of ceiling have been made.⁽⁵⁾

APPENDIX 4
MONITORING BRINE AND WATER MIGRATION
by
RESISTIVITY LOGGING

1.0 Introduction

The presence of accumulated brine adjacent to emplaced SURF canisters and the intrusion of major quantities of ground water into the vault from water tables penetrated by the vault shafts have been identified as parameters impacting health and safety risk during retrieval operations. The canisters elevated temperature could undergo rapid chemical corrosion in the presence of an electrolyte resulting in a loss of radionuclide containment integrity. The ability to monitor moisture content adjacent to a canister prior to retrieval would provide valuable information regarding the probable degree of corrosive attack and thereby impact radiological risk.

2.0 Summary and Conclusions

The presence of either accumulated brine adjacent to a canister or the presence of moisture in the salt as a result of major intrusion of ground water may be monitored using resistivity logging as follows.

- The resistivity of the baseline salt is expected to be roughly 10^5 ohm-cm for rock salt with 0.08% moisture.
- The resistivity of brine or water saturated with salt is roughly 1 ohm-cm.
- Borehole resistivity logging may be used to determine resistivity as a function of depth over distances of many meters.

3.0 Description of Instrumentation

Resistivity logging equipment consists of a power source, meters for measuring current and voltage, electrodes and cables.⁽⁴⁾ The power source is typically a low frequency sine wave oscillator of several watts. The electrodes are lowered down bore holes in the salt and the resistance determined by measuring the current at a set voltage potential. Resistivity systems are commercially available from which the resistance can be read directly.

4.0 Resistivity Logging

The resistivity of rock salt with varying concentrations of dissolved brine is expected to vary from a high of 4×10^{16} ohm-cm for pure salt to 10^6 ohm-cm for rock salt with impurities and 0.08% moisture to 1 ohm-cm for saturated brine. This variation of fifteen orders of magnitude in resistivity provides the basis for resistivity logging as a means of monitoring for accumulated brine and intrusion of ground water.

APPENDIX 5
MONITORING SPENT FUEL DISSOLUTION
by
NUCLEAR ACTIVITY LOGGING

1.0 Introduction

The loss of containment integrity of emplaced SURF canisters in the repository would result in migration of radionuclides. Reference to table 1 of the main body of this report indicates that 10 year old PWR SURF wastes would contain roughly 10^3 Ci of volatile fission products, another 10^3 Ci of semi-volatile fission products, and another 10^6 Ci of non-volatile fission products and transuranics per canister.

The mechanisms of dissolution of these radionuclides into the surrounding salt media and their subsequent migration involve complex radiochemical reactions. Experimental results, coupled with other considerations, indicate that unconsolidated salt does not constitute an effective barrier to gas-borne contaminants even if their transport were diffusion controlled. (19)

2.0 Summary and Conclusions

The following represents the results of investigations conducted on the development of a monitoring system for spent fuel dissolution.

- Monitoring spent fuel dissolution by nuclear activity logging would provide meaningful information on the containment integrity of emplaced SURF canisters.
- Geiger-Muller probes have the required sensitivity and range for data acquisition.
- The background level is expected to be in the low millirem per hour range. Contamination detected in the low millicurie range could therefore be detected.

3.0 Description of Instrumentation

Geiger-Muller (GM) probes are readily available commercially for the ranges of interest. Scaler rate meters which count the pulses due to tube discharge are used in conjunction with the GM tube. Coaxial cable of any length up to roughly 10 meters may be used without preamplification due to the high voltage discharge (i.e. typically 2000 VDC) of the GM tube. A commercially available hand held industrial GM probe and scaler rate meter would be adequate for these measurements.

4.0 Nuclear Activity Logging

Gross beta-gamma activity profiles at specified distances from emplaced SURF canisters provides a means of establishing activity levels to be encountered in retrieval excavations. To perform such measurements, Geiger Muller probes would be lowered down bore holes and activity profiles generated.

The background radiation level is expected to be in the low millirem per hour range. The release of roughly 10^3 Ci of volatile fission products could conceivably result in readings as high as hundreds of rems. However, due to geometric attenuation with distance from the canister, readings on the order of one rem at two meters distance from the canister would be expected.

The tenth value distance of rock salt shielding is on the order of 30 cm (1 ft). For ten year old PWR fuel, the activity level corresponds to roughly 10^6 rem per hour at one foot distance. Therefore, roughly 200 cm of salt would be required to shield the Geiger Muller probe from the canister so that local activity measurements might be made.

APPENDIX 6
MONITORING TEMPERATURE
by
THERMOCOUPLE MEASUREMENTS

1.0 Introduction

The measurement of temperature has been identified as an environmental parameter which has health and safety risk implications in retrieval operations. Temperature of the SURF canister and surrounding rock salt will determine canister corrosion, brine migration, salt creep and spent fuel dissolution chemistry. Temperature impacts radiological risk exponentially in the thermodynamics of each of these parameters.

2.0 Summary and Conclusion

The results of investigations performed on temperature monitoring systems appropriate for the SURF canisters in the salt repository are the following.

- Chromel Alumel type K thermocouples should be employed as the temperature sensor due to their corrosion resistance and required sensitivity.
- Permanent temperature histograms on each canister should be maintained so that the time integrated effects of corrosion, creep, brine migration and potentially spent fuel dissolution may be estimated prior to any retrieval operations.

3.0 Description of Instrumentation

The temperature monitoring system should consist of a thermocouple buried adjacent to the canister, connected by extension cables to a multiplexer in series with a potentiometer and strip chart recorder. The multiplexer should be set to automatically switch to sequential channels at predetermined intervals. Multichannel strip chart recorders should be used to retain a temperature histogram of each canister.

4.0 Thermocouple Measurements

To monitor the canisters for temperature type K Chromel Alumel, thermocouples should be employed because of their high corrosion resistance and required sensitivity.

The maximum temperature to be encountered for three year old nuclear waste is calculated to be 127°C (260°F).⁽²⁰⁾ The minimum temperature, the temperature of the salt before any waste is put in the mine, is 23°C (74°F).

Thermocouples with the appropriate extension cords should be emplaced adjacent to the canister or its sleeve and readings taken on a periodic basis and recorded.

The temperature history of each canister could provide a means of establishing the probable risk of canister containment degradation. The temperature of each canister will be a slowly varying function of time. Therefore, for an assumed retrieval following twenty five years of interim storage, readings taken once a year may be adequate.

APPENDIX 7
MONITORING FOR HEALTH PHYSICS RADIATION
by
AIR PARTICULATE MONITORING

1.0 Introduction

Health physics radiation monitoring will have a substantial impact on health and safety risk to both occupational workers and the general public. Many different monitoring programs would undoubtedly be ongoing simultaneously to meet the requirements of the technical specifications as contained in the operating license (e.g. environmental air and water sampling on and off site, film badge programs, urinalysis, etc.).

During retrieval operations, a significant risk factor is the breach in containment of the SURF canister with a puff release of volatile and/or colloidal micron sized powder. Another significant risk factor is the direct exposure to ionizing radiation from the SURF canister.

2.0 Summary and Conclusions

Radiation health physics monitoring will represent a substantial impact in risk to health and safety from retrieval operations. The following summarizes the results of investigations conducted.

- Radiation health physics monitoring will be conducted at the repository to meet the technical specifications of the operation license whether or not retrieval of SURF canisters ever takes place.
- Retrieval operations introduce two major potential impacts on health and safety risk, direct radiation exposure and inhalation of radionuclide contaminants from a breached canister.
- Engineered safeguards and administrative controls must be developed to prevent direct ionizing radiation exposure.
- Air particulate samplers should be used to detect airborne radionuclide contamination as a result of the breach of containment of a SURF canister.

3.0 Health Physics Radiation Monitoring

To monitor for a breach in containment of the SURF canister during retrieval operations, an air particulate sampler should be employed. A continuous air sample should be withdrawn in the vicinity of the retrieval operation and counted to determine the airborne contamination level. Such systems are commercially available from a variety of suppliers (Victoreen, Baird Atomic, Eberline, etc.). Although they do not have the sensitivity to detect contamination levels at maximum permissible concentrations⁽¹²⁾ for continuous occupancy (i.e. less than 10^{-6} μ Ci/cc) they do have the required sensitivity to detect millicurie quantities of radionuclides which would indicate breach of containment.

APPENDIX 8
MONITORING PACKAGE CONDITION
by
MATERIALS INSPECTION AND TESTING

SURF CANISTER
INSPECTION AND TESTING

1.0 Introduction

The ability to determine the containment integrity and the ability to predict the imminent failure of containment of a SURF canister in a salt repository prior to any potential retrieval operations have been established as safety related parameters. Under consideration as monitoring activities incidental to retrieval should be a periodic program of inspection and testing of the canisters. For an assumed retrieval after twenty five years of interim storage, data taken on an annual basis would provide meaningful data on containment deterioration rates.

2.3 Summary and Conclusions

A SURF canister inspection and testing program consisting of receiving inspection, periodic nondestructive ultrasonic testing, and statistical sample destructive testing has been investigated with the following recommendations.

- All SURF canisters received at the repository should undergo receiving inspection in which a data base on the inventory and package characteristics would be documented.
- All SURF canisters on a periodic basis should undergo nondestructive ultrasonic testing to detect meaningful changes in containment integrity such as cracks, corrosion and weld integrity.
- A sampling of emplaced SURF canisters should undergo destructive testing to determine the insitu time rate of change of degrading factors. A meaningful sample should comprise on the order of ten canisters per year.

3.0 Receiving Inspection

The objective of the receiving inspection operations should be to establish the acceptability of SURF canisters. The dimensional, metallurgical and structural quality of the package can be established through standard inspection techniques including ultrasonic and radiographic inspection of the as-received canister.

To establish the integrity of the canister will require a remote series of operations in a hot cell. Ultrasonic reflection techniques can be used to establish the degree of internal corrosion and the canister wall thickness. Placing the canister in an evacuated chamber with a nuclear detector on the line could determine the containment integrity of the canister.

Unfortunately, the spent fuel material is not readily accessible for chemical and physical analysis. Therefore, the SURF canister receiving inspection will in large part have to be based on the quality control operations at the packaging facility as regards the acceptability of the package contents. A gamma scan of the canister would, however, indicate the presence of hot spots, the isotopic make-up and the total activity of the SURF package.

4.0 Nondestructive Testing

The objective of the nondestructive testing operations should be to detect cracks, weld failure and corrosion of the SURF package early enough to prevent the loss of containment. The methods and instrumentation required to perform in-field inspection and nondestructive testing of the package have yet to be developed; however, based on experience thus far derived with high level waste and with nuclear reactor operations, it would appear that there is a high potential for ultrasonic testing applications. (2.) These inspection and nondestructive testing procedures will necessarily have to be done remotely using radiation shielding to prevent personnel exposure.

4.1 Ultrasonic Testing (U.T.)

Nondestructive inspection and testing of the canister can be performed using established ultrasonic testing techniques. An echo-ranging technique using very short sound pulses (0.1 to 2.0 microseconds) of ultrasonic frequency (5 to 15 megacycles) have been used in the past to determine the presence of material discontinuities such as macro-cracks, inclusions or voids in castings or welds up to 5 inches thick.⁽²²⁾ The wall thickness of closed pressure vessels of similar design as the cask and canister have been determined using ultrasonic techniques in which the time lag between initiation of the signal and its reflection from the inner wall surface is measured. This time interval is related to the wall thickness in the following way. Sound is a longitudinal wave phenomenon representing the propagation of compressional waves in an elastic medium. The velocity of propagation, V , of these waves depends on the ratio of the elastic modulus, E , of the material to its density, ρ , as

$$V = \sqrt{E/\rho}$$

The velocity of sound waves in the medium is then solely determined by the medium material properties. The relation between the frequency and wave length of signal is then:

$$V = v \times \lambda$$

Thus at very high frequencies in the ultrasonic range, the wave length of the signal is very short which makes it

possible to develop pulses of waves at the surface.

The velocity of sound in iron and soft steel is approximately 16,500 feet per second. Therefore, if the frequency used is 15 megacycles, the wavelength of a single vibration is on the order of 10^{-3} inches, and the reflection time interval for the SURF canister is on the order of 10^{-5} to 10^{-6} seconds.

The instrumentation required to perform ultrasonic testing consists of a megahertz sonic signal generator, a transducer of comparable frequency response, an amplifier, and an oscilloscope or electronic clock from which the reflection time interval can be determined. These tests have reportedly⁽²¹⁾ been used to establish corrosion rates of canisters of high level waste exposed to 100°C (212°F) in water and 600°C (1112°F) in air at Battle-Northwest. A test consists of scanning the surface with the horn of the signal generator and transducer and determining the reflection time from the inner surface or from a material discontinuity which might be present.

5.0 Destructive Testing

The destructive testing program would be based on the assumption that the degree of radiation damage material deterioration within storage units of similar design, construction, initial loading and age would be consistent. The extent of canister deterioration can be established through core sampling and laboratory material evaluation. Such analysis techniques as gamma spectroscopy to establish isotope migration within the canister, and metallurgical evaluation to determine the rates of corrosion and deterioration of the canister could be performed. A measure of chemical stability of spent fuel material could be obtained by determining the isotopic and chemical makeup of any gaseous compounds found in the void space of the canister.

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