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THERMAL IMPACT ON HOST ROCK OF GEOLOGIC REPOSITORY

CHING-HUA MOU, ASSOCIATE PROFESSOR
SCHOOL OF ENGINEERING TECHNOLOGY
SOUTH CAROLINA STATE COLLEGE
ORANGEBURG, SOUTH CAROLINA

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THERMAL IMPACT ON HOST ROCK OF GEOLOGICAL REPOSITORY

I. INTRODUCTION

Since nuclear era began forty years ago, nuclear power has been used not only for military purposes but for generating electricity and other peaceful use. Today there are over two hundred nuclear power plants operating around the world and many more are under construction. But nuclear power has its opponents, who argue that use of nuclear energy is dangerous and its waste is hazardous to the environment. While some of the nuclear power plants experienced problems on their operation as early as 1960's, nuclear waste has never become a serious problem until the late 1970's when most of the early - constructed nuclear power plants began to feel the space shortage for storing their own spent fuel rods. Since 1950 all the spent fuel has been packed and sealed in the canisters, stored on site for cooling, and waited for ultimate disposal in the future. After over thirty years of operation, the on-site storage spaces are being filled up with spent fuel at an alarming rate and the hope of expanding existing storage facilities is not possible for many plants. the corrosion and leakage of metal canisters created more problems in handling the nuclear wastes. Yet, a final legitimate radioactive waste disposal

technology has not been fully developed.

Treating and handling of nuclear waste is difficult mainly because it remains hazardous for long, long time. Heat generation from the wastes lasts several decades and radiation emission may continue for thousands of years. Proper treatment, storage, and disposal of those high-level radioactive wastes is not only necessary but also urgent. Various treatment and disposal techniques have been researched and proposed. While it is banned in the United States of America, recycling of the spent fuel is common in France, Belgium, Russia, West Germany, India, Italy, and Britain. The high-level liquid wastes produced during reprocessing are either stored in stainless steel tanks or vitrified for solidification first and then stored in the canisters for ultimate disposal. Although reprocessing technology has been well developed and can be used to minimize the amount of radioactive waste, the nuclear wastes produced today are destined not for reprocessing but long term storage or final disposal.

In addition to the reprocessing of spent fuel, the isolation technology has also been considered. It takes time for any radioactive waste to decay to a level which is acceptable to the environment. If the spent fuel and nuclear waste can be isolated from biosphere long enough, say 1,000 to 10,000 years, not necessary forever, there would not be any hazard. This is the key concept of most radioactive waste disposal or isolation technology.

Various alternatives have been suggested for disposing or isolating radioactive waste from biosphere, such as subsea disposal, outer space disposal, and underground burial. Among these alternatives, only the underground burial method, or geological repository, is feasible technically and economically at this time.

Sketch of a typical geological repository is shown in Figure 1. Different geological formations have been studied and considered as the possible host rocks for geological repository. A Waste Isolation Pilot Project (WIPP) was initiated and a site in deep salt bed near Carlsbad, New Mexico was chosen in 1975 by the then Energy Research and Development Administration for burial of all defense transuranic wastes. A potential repository site in Basalt at Hanford Reservation, Washington is undergoing a site characteristics study. A drilling rig was set up at the Hanford site for lowering the shaft around spring 1985. Volcanic tuff is being investigated at the Nevada Test Site. Granites are exposed at the surface in many parts of the United States and are being considered in several areas as potential host media for repository. An economical and dependable hydrofracture process, developed and conducted by Oak Ridge National Laboratory, has been used to inject the liquid wastes into deep bedded shale formation.

As mentioned previously, the most immediately feasible way of disposing nuclear wastes is to bury them in the man-made repositories 2,000 - 3,000 feet beneath the earth's

Figure 1. Typical repository tunnel and its stress distribution.

surface. To find a suitable site in underground rock for this purpose, extensive researches are needed: identify and characterize possible sites, develop the technology needed to design and construct those deep repositories, perform in-situ tests to determine the impact of heat on the host rock, and evaluate the pros and cons of different types of geological media.

Numerous researches have been conducted in those areas. However, even with the most advanced technologies in waste-form making, canister making, packing, sealing, and burying the wastes, no one can ever guarantee that the buried wastes will be kept in the repository forever or long enough without leaking and contaminating the environment. The canisters which contain the radioactive wastes may crack due to vibration, corrosion, and thermal impact, and cause leakage of radioactive nuclides. The geologic formation may crack due to tectonic movements or heat generated by the wastes.

This research was designed to search for better knowledge in the areas of isolating or confining the nuclear wastes within the locality of its disposal. The contents of the study are described as following.

Site visits were planned for obtaining rock samples, geological and hydrological information, and current field situations. Two such visits were made for the said purposes. One at the beginning of the study and the other one at the middle of the study. Assistance from Oak Ridge Associated Universities was obtained for arranging the visits

and sampling.

The rock analysis which includes the determinations of physical characteristics, size and distribution of fractures, and the hydrological properties of rock was conducted.

The initial stress of rock was estimated and analyzed based on the geological survey information collected during the site visits. Change in stress and its distribution in the rock due to excavation was investigated and predicted according to the repository geometry. Thermal effects on the magnitude and distribution of stress in rock was also investigated and predicted according to the repository geometry. Thermal effects on the magnitude and distribution of rock stresses were investigated under two different temperature conditions. Emphasis was placed on the development of fractures due to stress concentration at or near the repository openings.

Permeability characteristics of host rock were evaluated at three temperature levels. Series of permeability tests were conducted for determining the thermal effect on the hydrological characteristics of rock.

Most of the experiment mentioned above were performed according to American Society for Testing and Materials standard testing procedures. All rock samples were prepared at Lewis Engineering Lab, South Carolina State Collage.

The following goals were achieved from this investigation:

1. Better understanding of stress changes in host rock due to repository excavation and thermal impact.
2. Better understanding of the development of rock fractures and its effect on the hydrological characteristics of host rock.
3. To provide the technical information obtained from this study to the Office of Civilian Radioactive Wastes Management (OCRWN) with a hope that it may assist OCRWN in the decision making of selecting a repository site.

Due to limited time for this research, only one type of host media, granite, was included in the study.

II. DISPOSAL OF RADIOACTIVE WASTES IN GEOLOGIC REPOSITORY

In Sweden, disposal procedures of high level nuclear wastes start with an interim surface storage which could be as long as 40 years. Centralized interim storage facilities are commonly used to keep the spent fuel and waste packages at ground surface. The 40 years pre-disposal aging of the wastes at ground surface is intended to allow sufficient radioactive decay so that temperature of the repository can be kept low and their effects on corrosion of the waste canisters and on rock properties will be minimum.

After the waste canisters are placed into the burial holes, the cavity between canister and rock will be filled with a mixture of bentonite and quartz sand. By swelling, bentonite is expected to penetrate into every crack and fracture and form a tight seal around the canisters. The quartz sand in bentonite provide not only the structural stability also good thermal conductivity.

Groundwater and its movement in the rock plays a very important role in migration of radioactive nuclides from repository to biosphere. Permeability of the intact rock is usually very low ranging 10^{-10} to 10^{-13} m/sec. However, the groundwater movement in hardrock such as granite is largely confined to the micro-fractures and the permeability of the fractured granite could be several orders higher. Due to the uncertainty of rock conditions at depth an accurate prediction of groundwater travel time from repository to

human environment will be impossible. It could vary from few hundred years to 50 or 60 thousand years depends upon the thermal environment of rock, stress status, resistance of canisters to corrosion, performance of bentonite backfill, etc.

In this study, only the effects of excavation of repository and temperature change in repository on hydrologic property of granite are investigated.

III. MIGRATION OF NUCLIDES THROUGH ROCK FORMATION

Most of the nuclear waste packages are well constructed and a fairly high degree of structural stability and corrosion resistance are included in the canister design. In this country, the wastes are usually glassified and enclosed in a lead or concrete shield and placed in a canister which is usually made of stainless steel. In other countries such as Sweden, copper canisters are used instead of steel ones. Lead and concrete are used to provide shielding of radiation and stainless steel canisters provide structural stability and corrosion resistance. Other than the safety provisions mentioned above, a compacted backfill which consists 30 % of bentonite clay and 70 % of quartz sand is added between canisters and rock. This clay-sand mixture serves as cushion and sealer. It prevents direct contact between hardrock and canister surface. At same time it serves as barrier to seepage. However, the negative effects of the densely compacted bentonite-sand backfill on heat dissipation from waste packages must be addressed. Due to the low heat conductivity of bentonite clay, heat generated from wastes can not dissipate very easily and a heat built-up may occur in the waste packages. The temperature rise in the waste packages will accelerate the rate of corrosion and deterioration of the canisters.

The movement of nuclides begins when nuclear wastes are leached away from its storage site by groundwater. The

existence of groundwater and damaged canisters are necessary for any migration of nuclides to occur. Since most canisters are designed to last at least hundred years, no nuclide migration is to occur until then only if groundwater is available. Radioactive nuclides must penetrate the backfill and rock formation before reaching any human environment. This is a long journey considering the extremely low permeability of rock and clay and the extended distance between repository site and human environment. It may take one thousand to ten thousand years. During its journey through the rock, nuclides will continuously lose its radioactive strength due to the adsorption ability of rock. Hopefully, by the time it reaches the ground surface, its radioactive level will be low enough to be considered as safe to human being. In addition, large water bodies on the earth such as oceans, lakes, and rivers usually possess the ability of dilution of nuclides and can reduce the radiation level further down to a harmless range.

IV. HEAT GENERATION AND ITS EFFECTS

In most of the European countries, the underground repositories are the major means of disposing the nuclear wastes. The wastes are usually kept in a surface storage and cooling facility for forty years before being disposed into the underground repository. Since most of the heat and radiation have been disposed or released into the air prior to final burial, the nuclear wastes will not generate too much heat in the repository. Therefore the temperature of the rock near the opening will not be very high and usually ranges from 100 °C for saltbed to 200 °C for basalt. The disposal procedures of nuclear wastes in the United States of America are different. The wastes are cooled at a surface facility for only ten years before being placed in the geologic repository for final disposal. Because of short pre-cooling period for the wastes, tremendous heat will still be released from the wastes in repository during the first few decades and temperature of rock could easily rise to 300 °C or above before it begins to drop.

Most of the waste packages are buried and backfilled with compacted bentonite. Bentonite is used for two reasons: providing the best cushion between rigid waste package and hard rock and preventing waste from leaking. However, the compacted bentonite is low in heat conductivity. Most of the heat generated from the waste won't be able to dissipate

very easily. Accumulation of heat will accelerate the deterioration of the waste package and eventually lead to a leakage of wastes.

V. ROCK SAMPLES

Due to limited time, only one type of rock - granite was used for this investigation. The granitic rock was freshly excavated from a quarry near Cayce, S. C. in November, 1984. The quarry is owned by Martin Marietta Aggregates, Inc., based in Columbia, S. C., and the rock samples were provided by Martin Marietta for this study. The granite samples were excavated 325 feet below ground surface. Congaree River is only about a half mile away from the quarry. The river is about 300 feet higher than the excavation point. The rock at Cayce Quarry and the rock at Savannah River Plant in Aiken, S. C. are believed to be the same vein which runs from southern Georgia to central Pennsylvania.

The mineralogical contents were analyzed and determined by Martin Marietta and are shown in Table 1. Rock is grayish in color and mainly consists of quartz and feldspar. The grain size is less than 2 mm. The nature water contents range from 0.6% to 1.3%. The physical properties of rock were determined and listed as shown in Table 2. Unconfined compression tests were performed and a typical stress-strain diagram is shown in Figure 2. With the aid of split-tension tests on the same rock, a strength characteristic diagram was constructed and the angle of internal friction of rock was estimated as shown in Figure 3.

While the rock samples used in this investigation are

mostly intact, the rock mass at the quarry site shows vertical fractures. Fractures are formed parallelly with spacings which vary from 4" to 50". The fractures are approximately 0.006" and filled with clay in pink.

TABLE 1. MINERALOGICAL ANALYSIS OF GRANITE

<u>Minerals</u>		<u>Percentage</u>
Silicon	SiO ₂	72.27
Titanium	TiO ₂	0.29
Aluminum	Al ₂ O ₃	14.28
Iron	Fe ₂ O ₃	2.52
Manganese	Mn ₂ O ₃	0.05
Magnesium	MgO	0.33
Calcium	CaO	1.49
Sodium	Na ₂ O	3.49
Potassium	K ₂ O	4.25
Strontium	SrO	0.04
Phosphorus	P ₂ O ₅	0.06
Sulphur	SO ₃	0.01
Chlorine	Cl	0.01
Total		98.88

TABLE 2. PHYSICAL PROPERTIES OF GRANITE

Porosity %	Density pcf	Coeff. of Thermal Expansion in/in/°F	Young's Modulus psi	Poisson Ratio	Permeabi- lity cm/sec
0.828	159.2	4.5x10 ⁻⁶	1.8x10 ⁶	0.25	0.9682x 10 ⁻¹¹
1.470	171.1	9.1x10 ⁻⁶	6.4x10 ⁶		2.3458x 10 ⁻¹¹

TABLE 3. UNCONFINED COMPRESSION TEST RESULTS

(LOAD RATE = 0.01 IN./MIN.)

SPECIMEN NO.	TEMPERATURE DEGREE, F	DENSITY pcf	COMPRESSIVE STRENGTH psi	MODULUS OF ELASTICITY x10 ⁶ psi	REMARKS
C-02	300	163.70	16,973	1.80	
C-03	300	164.07	16,356	3.33	
C-04	70	167.45	22,000	6.40	
C-05	70	171.06	24,100	4.60	
C-06	70	163.16	20,400	4.60	Saturated
C-07	70	163.84	22,600	3.50	Saturated
C-08	70	163.20	16,420	3.30	
C-09	300	163.49	20,400	3.22	
C-10	300	163.93	17,100	3.03	
C-13	70	166.00	18,600	3.20	
C-14	70	163.86	14,800	2.00	
C-15	70	164.76	15,700	2.40	
C-16	70	164.94	19,800	2.65	
C-17	70	163.38	16,500	2.85	
C-18	300	164.04	14,000	2.50	
C-19	300	162.41	22,600	4.60	
C-20	300	164.67	19,200	2.50	
C-21	70	162.15	13,700	3.57	
C-22	70	163.50	11,600	2.56	
C-23	70	159.87	11,200	3.62	
C-24	70	160.25	13,300	2.75	
HC-31	300	166.10	25,240	4.50	
HC-32	300	166.95	18,420	2.60

Figure 2 . Stress - Strain Relationship

TABLE 4. SPLIT TENSION TEST RESULTS

SPECIMEN NO.	TEMPERATURE DEGREE, F	DENSITY pcf	TENSILE STRENGTH psi	LOAD RATE in./min.
1	70	163.28	1,732	0.05
2	70	166.35	2,295	0.05
3	70	163.94	1,108	0.05
4	300	163.37	1,361	0.05
5	300	163.82	1,723	0.05
6	300	162.55	1,676	0.05
C-4A	70	167.27	1,593	0.05
HT-1	300	165.03	2,055	0.05
HT-2	300	163.68	1,125	0.05
HT-3	300	162.13	996	0.05
HT-11	300	165.30	1,368	0.01
HT-22	300	164.46	1,975	0.01
ST-11	70	163.19	1,595	0.05
ST-12	70	164.25	1,488	0.05
ST-13	70	163.30	2,151	0.05
T-11	70	166.23	1,440	0.01
T-12	70	167.51	1,948	0.01
T-13	70	164.55	2,372	0.01

Figure 3. Failure envelope

VI. IN-SITU STRESSES OF ROCK

The stress status in the rock varies from point to point. It changes when rock formation alters or disturbed physically. The initial stresses in the rock will be redistributed when repository excavation begins. After the construction of repository, rock stresses will experience another change when nuclear wastes are buried and sealed in the repository. Therefore, the stress distribution in rock is to be discussed according to the following sequence.

a. Before Excavation

The initial stresses in the rock are usually closely related to the geological history of the formation and the depth of the rock. If the ground surface is level, the in-situ vertical stress equals the weight of overburden which is the product of unit weight and depth. At a depth of 3000 ft., vertical stress will be in the neighborhood of 500,000 psf if the rock unit weight is 165 pcf. This compressive stress is well below the compression strength of rock. The horizontal stress varies with the vertical stress and the ratio of horizontal stress to vertical stress also varies with depth. This ratio, also called horizontal stress coefficient, ranges from 0.3 near ground surface to 1.0 at depth. In general, both vertical stress and horizontal stress increase with depth and remains constant at same depth. At the depth where repository is built, only

compressive stresses are found and shear stress is usually very small, therefore no large openings or cracks are expected. A stress distribution diagram is shown in Figure.1. It is often possible to estimate the magnitude of rock stresses and their directions but one can never be certain of the margin of error without actual measurement.

b. After Excavation

Construction of repository alters the geometric configuration of the rock formation and results in a redistribution of loads and stresses in rock. Each repository consists of a three dimensional array of openings including vertical shafts, horizontal tunnels, and other operating/maintenance rooms. Openings in the rock cause changes in the initial stress when they are constructed. In order to simplify the analysis, a horizontal tunnel with a cross-section shown in Figure 1 is used. Due to the removal of vertical support and horizontal confinement, stresses of the rock near the opening will be redistributed. The stress distribution diagram shown is based on elastic analysis. By examining the stress distribution near the opening, higher stress concentrations were noticed at various places especially lower corners and shoulders. A stress concentration factor of 2.5 was calculated at lower corner. Side wall shows a vertical stress increase and a horizontal stress decrease. Bottom (floor) and top (crown)

of the opening show decrease in vertical stress and increase in horizontal stress. The increase in horizontal stress is particularly critical, especially at bottom of the tunnel, because of the change of stress status from compression to tension.

Development of tensile stress in the rock always accompanied with an increase in size of voids or development of new cracks if tensile stress and thermal characteristics of rock is to be affected. Permeability of rock is to increase and the groundwater movement will be faster. It also means that the nuclides leached from repository will reach the ground surface at a faster rate. Fortunately, this will occur for only a very short period of time. The temperature built up in the rock near the opening, especially the spots where nuclear wastepackages are buried will begin to show the effects on rock permeability on the negative side several years after the emplacement of wastepackages. A decreasing in permeability will be the result of this temperature rise in rock. This, on the other hand, will lead to a slow movement of groundwater toward ground surface. The overall impact of repository excavation and heat build up on rock permeability are not very easy to be evaluated.

c. Stress Distribution After Emplacement of Wastepackages

Most nuclear wastes emit radiation and generate heat simultaneously, even when they were buried in the rock. If

the entire wastes are confined or isolated in the repository, release of radiation can be prevented but heat will still be generated and transmitted toward outside. Therefore a heat build-up occurs within the vicinity of repository. Since rocks are relatively confined, temperature rise causes tremendous thermal stress in the rock which in turn will reduce the voids or even close up the cracks.

VII. PERMEABILITY OF ROCK

Rock has been used as construction material for years. Most of time, rock was utilized for supporting loads, such as footing, column, wall , and slab. A through understanding of mechanical properties of rock is necessary for achieving a satisfactory structure design. But when rock formation deep in the ground is used as repository for radioactive wastes, not only mechanical behavior of rock is needed, the hydrological characteristics of rock plays an important role too. Rock has been considered as a good barrier to prevent the leakage of radioactive wastes from geological repository to biosphere. Evaluation of rock permeability , therefore, becomes a very important step in estimating the time required for radioactive wastes being leached back to human environment.

a. Rock Permeability Test Apparatus:

A new method of testing rock's hydrologic property has been investigated and developed. The new method requires only a moderate pressure and has the ability to detect a very small amount of water flow through rock samples. New device also has the capability of measuring rock permeability at various temperatures range from 70°F to 130°F.

A metal chamber with base, ring, and cover is connected to compressed air supply. Rock sample is placed and

FIGURE 4. SCHEMATIC DIAGRAM OF ROCK PERMEABILITY TEST APPARATUS WITH TEMPERATURE CONTROL

cemented to the base and divides the chamber into two parts: upper chamber and lower chamber. Lower chamber has one outlet and is connected to a long capillary glass tube. Upper chamber is filled with deaired distilled water and a compressed air is introduced to the top of water. Lower chamber is also filled with deaired distilled water but in contact with atmosphere. Due to the pressure difference in upper chamber and lower chamber, water flows from upper chamber to lower chamber through rock sample. By measuring the movement of air-water interface in capillary tube, amount of flow can be determined.

The permeability of rock is determined by using Darcy's formula:

$$k = \frac{Q \times L}{\Delta t \times \Delta H \times A}$$

where k = permeability of rock, cm/hr
 Q = total amount of water flow through rock sample during time interval Δt
 Δt = time interval, hours
 L = thickness of rock sample, cm
 ΔH = pressure difference between upper chamber and lower chamber, cm of water column
 A = cross-sectional area of rock sample, cm²

Rock specimens were cut from large intact rock piece into 0.650 cm or 1.00 cm slices. Each slice was then divided, rounded, sanded, and grinded to 5.0 cm diameter disc to fit into the device. Water was used for cooling in preparing the rock specimens. Each rock specimen was oven-dried at 250 °F for 48 hours and cooled before being cemented

rock specimen was achieved by introducing vacuum to the lower chamber while upper chamber was filled with deaired water. Evacuation process required a minimum of four hours. Six hours was used for this study.

c. Rock Permeability Test Results:

The results of rock permeability test are summarized in Table 5 and Figure 5. The specimen size and air pressure used for each test are indicated in the remarks. The test results show that the permeability of rock varies from 0.9×10^{-11} cm/sec to 2.4×10^{-11} cm/sec and is independent of the applied air pressure. Different air pressures were used to provide the same hydraulic gradient for each test set. The permeability result of 1.0×10^{-11} cm/sec for an intact granite is very consistent with the results from other investigators. The effects of rock density on its permeability were not evaluated because all rock samples used for this study are from the same source. The difference in density is not appreciable enough to study the effects.

The effects of temperature on rock permeability were investigated and three temperature levels were used for the evaluation. Due to the limitation of testing device, the highest temperature was set at 120 °F. A higher temperature of 150 °F was used for preliminary study and air bubbles were detected underneath the rock sample. Creation of air bubbles in the lower chamber due to high temperature and low

TABLE 5. RESULTS OF ROCK PERMEABILITY TESTS

Specimen No.	Density pcf	Temperature Degree, F	Permeability $\times 10^{-11}$ cm/sec	Remarks
				Set #1
1-1	163.4	76	1.1743	
1-2	165.2	76	1.0388	
1-4	164.8	76	1.2112	Diameter
1-11	164.1	100	1.3830	=4.75 cm
1-12	163.8	100	1.3342	Thickness
1-22	165.3	120	1.6320	=0.635 cm
1-24	162.7	120	1.8452	Pressure
				=60 psi
				Set #2
2-2	164.7	76	0.9682	
2-3	163.2	76	1.1342	
2-11	164.3	100	1.2172	Diameter
2-21	165.0	120	2.3458	=6.30 cm
				Thickness
				=0.980 cm
				Pressure
				=100 psi

FIGURE 5. PERMEABILITY VS. TEMPERATURE CURVES

pressure resulted an unreasonably high permeability. To be certain that this is not to happen, a temperature of 120 °F was used as upper limit. Use of higher temperature is possible if the pressure in lower chamber can be raised. This modification of test apparatus could be the research in the future. The test results indicate an increase in permeability with temperature. This is true when a unconfined rock sample is used because the high temperature usually reduces the viscosity of water and increase the porosity of rock. However, for a confined rock condition such as underground repository, higher temperature usually close up most of the fine fractures and openings in the rock which may result a reduction of permeability. This situation has been experienced at Stripa, Sweden when a field permeability was conducted in the boreholes at high temperature. In that study, it was found that not only the water flow rate dropped, it eventually stopped.

New rock permeability test apparatus and procedures were developed and tests were performed using granite as rock samples. The apparatus worked fairly satisfactorily and a permeability as low as 0.9682×10^{-11} cm/sec was measured on intact granite samples.

VIII. EFFECTS OF TEMPERATURE ON ROCK STRESS AND PERMEABILITY

Although as mentioned previously, the nuclear wastes and spent fuel packages were cooled off at ground surface interim storage sites for ten to forty years before being stored in a permanent underground repository, heat will continuously generate from the radioactive wastes for decades in the repository. Therefore, a temperature rise in the rock formation near repository opening will occur few years after emplacement and it may take ten to twenty years to reach a peak. Temperature change in rock, especially in the vicinity of repository opening, always cause the redistribution of stress and strain in the rock. Volume change in rock is usually accompanied by a change in voids or size of fractures which in turn will cause a change in rock permeability.

a. Stress Redistribution Due To Temperature Build-up In Repository

Immediately after construction of repository, the stress status in rock will begin to change. While most of rock experience minor changes in compressive stress, certain portions of rock will show dramatic changes in both magnitude and direction of stress. Based on the computer analysis using ANSYS-PC/ED version from Swansons Analysis, Inc., the compressive stresses along the sidewalls increase 1.5 times

and at the lower corner 2.5 times. The finite element analysis also shows that tensile stresses will develop at top crown and bottom floor of the repository tunnels. Relatively high horizontal tensile stress can be noticed at the flat bottom. Although the maximum tensile stress is still lower than the tensile strength of rock and no cracks is to occur in the rock, an increase in porosity is always a possibility. The higher rock porosity means higher permeability which is very critical to the design of a safe and reliable repository for nuclear wastes.

When radioactive wastes are placed and buried in the repository, heat begins to generate from the wastes. The rock near the repository will experience a temperature rise for many years. According to the previous field investigations conducted in Europe, the peak temperature in rock usually occurs about fifty years after emplacement of wastes in the repository. When an unconfined rock is subject to heat built-up, its volume increases and its internal stresses remain unchanged. However, the rocks at repository level are well confined with a horizontal stress factor ranges from 0.8 to 1.0. The temperature increase in a confined rock usually cause reduction in voids and increase in compressive stress. After the temperature in repository reach its peak level, probably fifty years after emplacement as mentioned above, a slow temperature drop is to continue for many years. Lowering of rock temperature will cause rock mass to shrink and crack. The development of cracks

and fractures will dramatically increase the permeability of rock near repository site. The compressive stress in rock will decrease due to temperature drop. Further study is needed for better understanding of the effects of temperature on rock stresses.

b. Effects Of Temperature On Rock Permeability

Temperature rise near repository will cause compression in rock and reduce the size of voids. Although the density of rock remains practically the same, the permeability of rock is to decrease appreciably. Long-term response of rock mass to heat and cool has not been studied in depth. Test results by Lundstrom and Stille indicate that thermally induced compressive stresses tend to reduce the permeability of rock. This is in consistence with the findings at Stripa, Sweden in a field permeability test. Because of the large number of variables involved in the evaluation of rock permeability, it is essential that both laboratory and field studies concentrate on site-specific rock type under the appropriate repository environment.

Test results from this study indicate an increase in permeability when rock temperature rises. This is a valid trend for an unconfined rock sample such as the one used in this investigation. The same correlation may not be applicable to the rock in the field such as a deep repository site.

IX. CONCLUSIONS

Basic concepts of desposing the nuclear wastes in a geologic repository was discussed. Effects of repository construction on rock stress distribution were studied. Heat generation within the repository and its impact on rock stresses and rock permeability were investigated. New apparatus and procedures for rock permeability determination were developed and tested. After the year long study, following conclusions are drawn:

1. Excavation of repository results a redistribution of stresses in the rock near the repository opening. Relatively high tensile stress occurs at both roof and floor of repository, which is very critical to the safety of disposing nuclear wastes in repository as far as leakage and migration of nuclides are concerned.
2. Thermal stresses caused by heat build-up in the repository can alter the stress status in rock. While heat build-up accelerates the deterioration of waste canisters and causes leakage of nuclides, the heat induced stresses close up the fractures in rock and reduce the rate of groundwater movement. The net impact of heat on the repository performance is not clear.
3. A new rock permeability test apparatus and procedures

were developed and used in the study. The details about the new apperatus were described and the results of the permeability test on rock were presented and discussed.

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