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PRECLOSURE VOLCANIC EFFECTS: EVALUATIONS FOR A POTENTIAL REPOSITORY SITE AT YUCCA MOUNTAIN, NEVADA

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ABSTRACT

Potential volcanic effects during the preclosure period of a waste repository at Yucca Mountain include those caused by nearby basaltic eruptions and more distal silicic eruptions in the western Great Basin. The volcanic effects from nearby basaltic eruptions during the preclosure period are considered negligible because of the low rate of basaltic volcanism in the Yucca Mountain area and because the disruptive effects of basaltic volcanism are generally confined to a small area around the eruption site. The most likely volcanic effects during the preclosure period would be from a silicic eruption in either the Coso or the Long Valley area on the western margin of the Great Basin. Based on the previous volcanic history of these areas, an eruption during the preclosure period would probably involve only a small volume (<1 km^3) of erupted material and would deposit no more than 1 cm of ash in the Yucca Mountain area. This poses only a minimal potential hazard to operations of repository facilities.

1. INTRODUCTION

Volcanism studies are being conducted for the Nevada Nuclear Waste Storage Investigations (NNWSI) to determine the hazards of future volcanic activity with respect to the possible siting of a repository at Yucca Mountain for the permanent storage of high-level radioactive waste. Past studies have been concerned with the long term volcanic hazards for waste disposal. The long term refers to the hazards during the 10^4 year containment period as specified in the draft version of the Environmental Standards for Management and Disposal of Spent

Nuclear Fuel. High-Level and Transuranic Radioactive Wastes [U.S. Environmental Protection Agency (1982) 40 CFR 191]. This work has been described in a number of reports and is summarized and referenced in three status reports (Crowe and Carr. 1980: Crowe et al.. 1983a: and Crowe et al.. 1986). A lesser problem is the question of the potential volcanic hazards during the preclosure period of a waste repository. The Nuclear Regulatory Commission has specified in 10 CFR Part 60 (1983) that ". . . (the) ability to retrieve—retrievability—be incorporated into the design of the geologic repository." The originally proposed rule required that the repository be designed so that retrieval of waste packages was possible for a period of up to 110 years. This length of time was based on an estimated 30 years for emplacement of high-level waste. 50 years to confirm the performance of the repository and an additional 30 years in which the waste could be retrieved (total of 110 years). Review comments received by the Nuclear Regulatory Commission concerning the Retrievability section suggested that the length of time of the proposed requirement was excessive. They therefore modified the requirement to ". . . the design should allow retrieval to be undertaken at any time within 50 years after commencement of emplacement operations . . .". The Nuclear Regulatory Commission further noted that the 50 year time period could be modified depending on the emplacement schedule and the confirmation program for a specific repository site. Because of this retrievability requirement. we have conducted preliminary assessments of the possible impact of future volcanic activity during this 50 year period (referred to as the preclosure period) Our assessment is concerned with the possible interference to the required operations of a repository during the preclosure period. We have not assessed concerns with the radiological safety of the repository. Because the design of the potential repository at Yucca Mountain is in the conceptual stages. we additionally have not attempted to evaluate the specific impact of volcanic eruptions on surface facilities. Our approach for this assessment is to describe the likely magnitude of potential volcanic effects during the preclosure period. If the site is considered for licensing and the design of the repository and facilities is further developed. the hazards from volcanic activity on surface facilities can be assessed using information from this paper.

II. PRECLOSURE ASSESSMENT OF POTENTIAL VOLCANIC EFFECTS

The effects of volcanic activity during the preclosure period of a repository can be divided into two topics:

1. The preclosure effects from volcanic activity adjacent to Yucca Mountain.
2. The preclosure effects from distal volcanic activity west of the Yucca Mountain site.

III. VOLCANIC EFFECTS - YUCCA MOUNTAIN AREA

The most likely form of future volcanism in the Yucca Mountain area is basaltic volcanism (Crowe et al., 1983b). The calculated probability of disruption of a repository by basaltic volcanic activity is bounded by the range of 5×10^{-8} to 3×10^{-10} per year (Crowe et al., 1982). The upper bound for this calculation is 3×10^{-6} for the preclosure period (assuming a 50 year preclosure period). This number is considerably smaller than 1 chance in 10,000 and therefore this event is too unlikely for further consideration during the preclosure period. The probability of volcanic disruption of a repository (Crowe et al., 1982) was designed for the case of direct intrusion of magma into the repository block. It does not consider the case of damage to or hampering of the operations of surface facilities of a repository during the preclosure period. The probability of these effects can be considered by modifying the parameters of the probability formula. The probability formula for direct intrusion is (Crowe et al., 1982):

$$\Pr[\text{no disruptive event before time } t] = exp^{(-\lambda tp)}$$

where λ is the rate of volcanic activity and p is the probability that an event is disruptive. The p is an estimation of the probability that given a volcanic event (rate dependent), that event will intersect the repository site of interest. It is formulated as an area ratio of a/A, where a is the area of a repository or of an assigned volcanic disruption zone (whichever is larger) and A is some minimal area that encloses the repository and the volcanic events used to describe λ (Crowe et al., 1982). The area of volcanic disruption from a basaltic eruption is small and the a becomes the area of the repository. The probability of surface effects from basaltic volcanism during the preclosure period are evaluated by determining how these effects would change the a in the area ratio. The conserva... ...tion is made that a scoria deposit of 1 meter thickness from a basaltic eruption would have unacceptable effects on the surface facilities or operations of a repository. This thickness of scoria would most likely not cause structural damage but would increase the difficulty of operating a repository during the retrievability period. The changes in the a of the area ratio for this case can be evaluated using the data presented in Crowe et al. (1983b. Fig. 6) A 1 meter thickness of a scoria fall sheet is expected to occur approximately 3 kilometers from a basaltic vent [using the Carvao "C" fall deposits (Booth et al., 1978) as a conservative representative of a Strombolian eruption]. Assuming a square repository with an area of 8 km^2. the a in the area ratio would be increased to about 78 km^2 by including the area that could be covered by a scoria fall deposit of 1 meter thickness. This increases a in the area ratio by about an order of magnitude over the calculated case of direct intrusion of a repository and changes the worst case probability bound to 3×10^{-5} This probability factor is still smaller than 1 chance in 10.000 of significant volcanic effects during the preclosure period. We conclude that the probability of effects from basalt volcanic activity is sufficiently low that the hazards for a repository at Yucca Mountain are negligible during the preclosure period.

IV. DISTAL VOLCANIC CENTERS WEST OF THE YUCCA MOUNTAIN AREA

The main effect on a repository in the Yucca Mountain area during the preclosure period would be the accumulation of volcanic ash produced by distal silicic eruptions. Three volcanic areas within the western Great Basin (Long Valley/Mono-Inyo craters. Coso. and Big Pine) have undergone recent silicic volcanism. and, by virtue of their location (Fig. 1). the recurrence of silicic volcanism within these volcanic fields during the preclosure period could affect a repository at Yucca Mountain. The eruptive history of these volcanic areas is reviewed below.

A. Coso Volcanic Field

The Coso volcanic field is located on the western margin of the Great Basin about 150 km southwest of Yucca Mountain. The volcanic geology of the Coso area, including timing and volume of eruptive events, is well known from work by Duffield (1975). Lanphere et al. (1975). Duffield et al. (1980). Bacon et al. (1981). and Bacon (1982). K-Ar dating has defined two

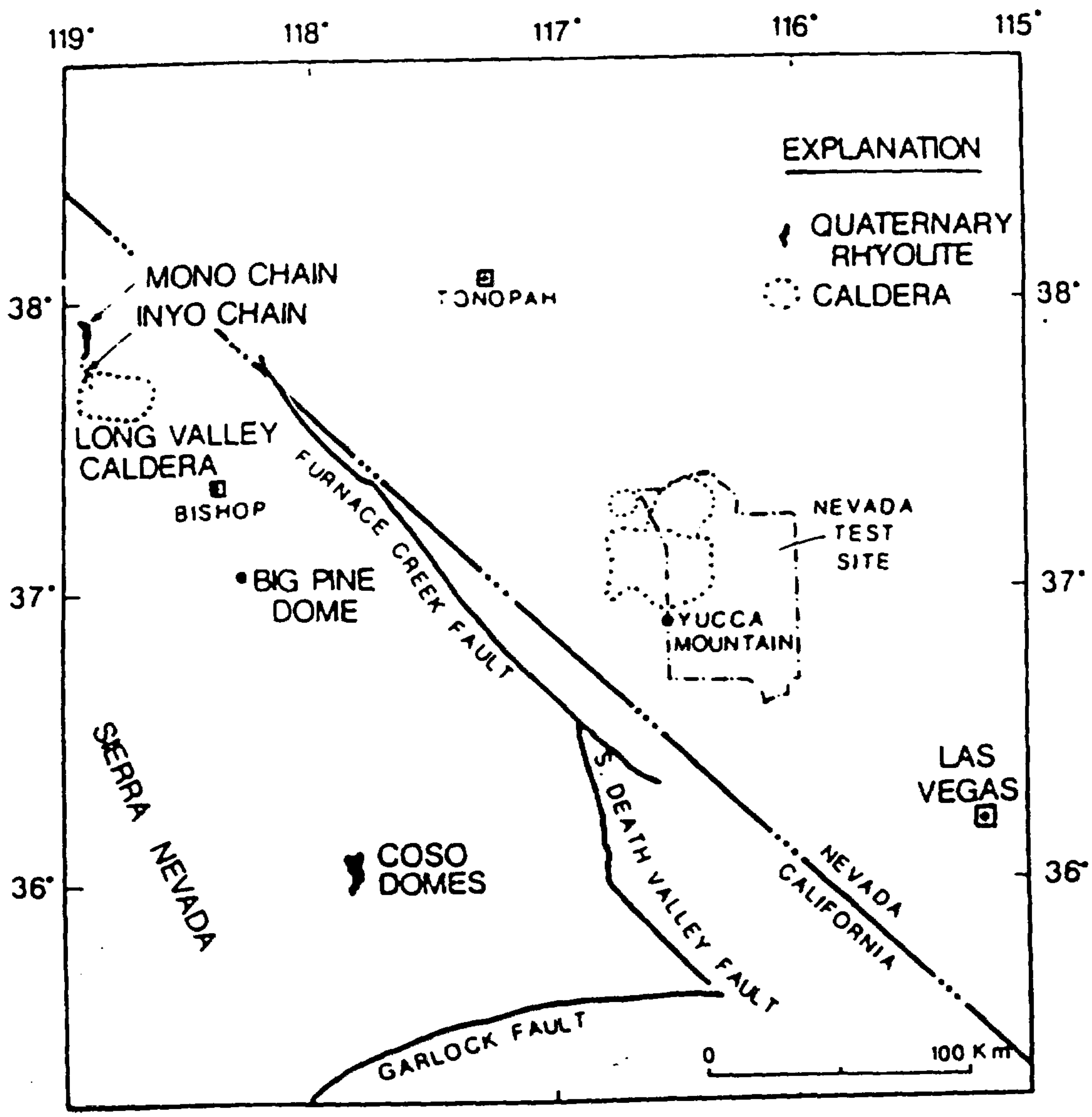

Fig. 1. Location of Quaternary silicic volcanic centers in the western Great Basin.

periods of volcanism within the Coso field: (1) 4.0-2.5 m.y. ago, eruption of approximately 31 km^3 of basalt, andesite, dacite, rhyodacite, and rhyolite, constituting about 90 percent of the volume of volcanic rocks within the volcanic field, and (2) 1.1-04 m.y. ago (the "bimodal" period), about 1 km^3 of basalt and 2 km^3 of rhyolite were erupted, with most of the rhyolite erupting < 0 25 m.y. ago (Lanphere et al. 1975; Duffield et al., 1980).

Rhyolites of the bimodal period occur as 38 domes and lava flows. Thirty six of the domes and flows are younger than 0.25 m.y. old and can be grouped, on the basis of K-Ar ages, obsidian hydration-rind ages, field relationships, and geochemistry into 5 eruptive episodes. Each eruptive episode occurred during a geologically brief time at 0.235, 0.170, 0.16, 0.089, and 0.063 m.y. ago (Lanphere and other, 1975; Duffield et al., 1980; Bacon et al., 1981). The time interval between these eruptive episodes ranges from 71,000 years to 10,000 years. The cumulative volume of these domes and flows is 1.53 km^3, with the volume of individual domes and flows ranging from .0003 km^3 to 0.3 km^3. Volumes of individual eruptive episodes range from 0.12 km^3 at 0.17 m.y. ago to 0.66 km^3 in the youngest episode at 0.063 m.y. ago (Bacon et al., 1981).

Bacon et al. (1981) and Bacon (1982) noted a systematic relationship between the volume of rhyolite erupted during each of the five episodes and the time interval between each eruptive episode. Specifically, the interval between eruptions is related to the volume of the preceding eruption so that a small volume eruption is followed by a relatively short repose period before the next eruptive episode and larger volume eruptions are followed by relatively longer repose periods. Bacon et al. (1981) and Bacon (1982) used this systematic relationship, which has held for the past 0.25 m.y., to predict that the next rhyolite eruption in the Coso field will occur 60,000 ± 35,000 years in the future. Because the most recent rhyolite eruptive episode in the Coso field was also the most voluminous (0.66 km^3), the repose time between the last eruption and the time of the next predicted eruption (~120,000 years) is longer than any of the previous repose periods.

Small volume explosive pyroclastic eruptions of pumice and ash preceded extrusions of some of the rhyolite domes of the bimodal period. The minimum volume of pyroclastic material erupted during the bimodal period was 0.3 km^3 (Bacon et al., 1981). Almost all of the pyroclastic deposits are confined to the area of the volcanic field, and today form a thin cover over most of the volcanic field (Bacon et al., 1980, Fig. 1). The original thickness of this deposit probably averaged 1 to 2 meters (Duffield et al., 1980). Obsidian fragments found as far as 20 km to the east of the Coso volcanic field indicate the minimum distance that pyroclastic material from the Coso field was dispersed (Duffield et al., 1980).

B. Long Valley Area

The Long Valley area is located at the western margin of the Great Basin along the eastern base of the Sierra Nevada about 250 km west-northwest of Yucca Mountain. Silicic volcanism younger than 1 m.y. old in the Long Valley area can be divided into two episodes based on location and timing of eruptions. The earliest episode (the "caldera episode") began with eruption of the Bishop Tuff and formation of the Long Valley caldera 0.71 m.y. ago. Eruption of silicic domes and flows continued episodically within the caldera and along the caldera rim until about 50,000 years ago (Bailey et al., 1976). The most recent episode of silicic volcanism (35,000 to 550 years ago) produced the Mono and Inyo chains of domes and craters which extend from the northwest margin of the Long Valley caldera northward to Mono Lake, a distance of about 30 km (Bailey et al., 1976; Wood, 1977; Miller, 1985; Sieh and Bursik, 1986).

1. **Long Valley Caldera.** Silicic volcanism associated with the Long Valley caldera began with eruption of the Bishop tuff and formation of the caldera 0.71 m.y. ago. The volume of magma ejected during this eruption was about 600 km^3 (Bailey et al., 1976), making it one of six major caldera-forming eruptions that has occurred in the western United States during the past 2 m.y. The eruption of the Bishop Tuff produced ash falls of various thicknesses over much of the western United States and was the only eruption of the caldera episode to eject large volumes of eruptive material outside of the confines of the caldera. Following caldera formation until about 0.63 m.y. ago a group of rhyolite domes, flows and tuffs was erupted within the caldera and filled parts of the caldera floor to a thickness of at least 500 meters (Bailey et al., 1976). Starting at about 0.5 m.y. ago, and recurring at about 0.3 and 0.1 m.y. ago, a series of rhyolite domes were erupted within the caldera moat (Bailey et al. 1976). A series of rhyodacite domes and flows were then emplaced along the rim of the caldera

beginning about 0.15 m.y. ago and continuing until 0.05 m.y. ago (Bailey et al., 1976)

Since 1979, a series of seismic and tectonic events in the Long Valley area raised concern about the possibility of future volcanic activity and led to the issuance in May, 1982 of a "notice of potential volcanic hazard" for eastern California by the U.S. Geological Survey. This activity includes uplift of the resurgent dome within the caldera (~0.5 meters of uplift since mid-1979), accompanied by earthquake swarms in the southwestern moat zone of the caldera and in the granitic terrain south of the moat zone (Hill et al., 1985). Seismic data from a number of workers (referenced in Rundle et al., 1986) indicate that a large magma chamber (500-1000 km^3) still exists beneath the Long Valley caldera and that the top of the chamber is now 4 to 5 km beneath the southern portion of the resurgent dome. The recent uplift of the resurgent dome has been attributed to the injection of 0.1 to 0.2 km^3 of new magma into the magma chamber (e.g., Savage and Clark, 1982; Hill et al., 1985), indicating that this chamber is still active and capable of erupting in the future. The magnitude of a potential future eruption could range from 1 or several km^3 to as great as the 0.71 m.y. eruption of the Bishop Tuff (600 km^3). The timing of a future eruption from Long Valley, however, cannot be predicted. Seismicity within the caldera peaked during January, 1983 and has declined to a low level (<2 M=1 events per day) in the last few years (Hill, 1987). The Long Valley area is being monitored by the U.S. Geological Survey to provide warning of renewed volcanic activity. We are following the results of this monitoring and are continually evaluating the importance of activity at Long Valley to volcanic studies for the NNWSI.

2. Mono and Inyo Craters and Domes. The youngest silicic volcanism in the western Great Basin occurred in the Mono and Inyo chains with silicic eruptions occurring in both chains about 550 to 650 years ago, based on ^{14}C ages and dendrochronology (Miller, 1985; Sieh and Bursik, 1986). Emplacement of rhyolite domes began in the Mono chain at about 35,000 years ago (Wood, 1977, 1983), but 20 of the 24 exposed domes and flows in the Mono chain are estimated to be less than 10,000 years old, based on obsidian hydration rinds (Wood, 1984). The most recent and best studied eruptions in the Mono chain occurred in the northern part of the chain between 660 and 620 years ago (Sieh and Bursik, 1986). These eruptions began with explosive eruptions of ash followed by the emplacement of five domes and flows, all within a period of a few years. The total volume of ash fall deposits from the northern Mono eruptions is about 0.42 km^3 This volume consists of numerous individual ash fall beds representing many separate eruptive episodes. Volumes of individual ash fall beds range from 0.012 km^3 to 0.16 km^3 (Sieh and Bursik. 1986). Volumes of the five rhyolite domes and flows range from 0.002 km^3 to 0.385 km^3 with a total combined volume of 0.44 km^3 (Sieh and Bursik. 1986). Seismic studies indicate that a magma chamber with a melt volume of between 40 and 120 km^3 presently exists beneath the Mono chain with a top at about 8-10 km depth (Achauer et al.. 1986).

The Inyo chain consists of 7 rhyolite domes and flows and associated pyroclastic deposits. as well as numerous phreatic craters. The oldest Inyo dome is estimated to be 6000 years old and the youngest eruptions involved the emplacement of three domes and associated pyroclastic eruptions between about 650 and 550 years ago (Miller. 1985). The total volume of magma erupted from all of the Inyo vents is estimated by Miller (1985) to be 0.8 km^3. with 40 percent of this volume consisting of pyroclastic material. Volumes of individual domes range from <0.001 km^3 to 0.17 km^3 with the three youngest domes having the greatest volumes of 0.10. 0.13. and 0.17 km^3 (Miller. 1985). The volume of pyroclastic material associated with emplacement of the three youngest domes is about 0.26 km^3. with individual eruptive volumes ranging from 0.02 to 0.15 km^3 (Miller. 1985).

C. Big Pine Volcanic Field

The Big Pine volcanic field is located in the western Great Basin about 160 km west of Yucca Mountain and is comprised mostly of basaltic cinder cones and lava flows. A single rhyolite dome occurs in the field and has a K-Ar age of 0.99 m.y. (Cox et al.. 1963). Pyroclastic activity associated with this dome was apparently of small volume and most deposits have been removed by erosion.

V. AIR FALL PLUMES

Detailed data on dispersal direction. extent. and thickness of ash fall deposits from silicic centers of the western Great Basin are available only for the most recent eruptions of the Mono and Inyo chains of the Long Valley area and for the Bishop Tuff. the eruption of which formed the Long Valley caldera.

A. Dispersal Axes

Prevailing winds at the time of an eruption commonly cause airfall material to be distributed asymmetrically around the vent area. The region directly downwind from an eruption will therefore be affected more by ash fall than regions away from the downwind axis. Wind direction data for the Great Basin region cited in Miller et al. (1982) show that winds between 3000 and 16000 meters elevation blow toward a sector between N. 45°E. and S. 45°E. more than 50 percent of the time annually and in the broader sector easterly of due north and due south more than 80 percent of the time annually .

The dispersal axis directions for the northern Mono eruptions of 660 to 620 years ago are dominantly to the north or northeast (6 of 8 measured airfall beds. Sieh and Bursik. 1986). The exceptions are one airfall with a dispersal axis to the north-northwest. and another which was dispersed dominantly to the northeast but also to a lesser extent to the southwest. indicating shifting wind conditions.

Four airfall plumes were produced by the most recent (650 to 550 years ago) eruptions of the Inyo chain. Two of these plumes were dispersed to the northeast. and two were dispersed to the south and south-southwest (Miller. 1985).

The voluminous ash produced by the Bishop Tuff eruption was carried predominantly to the east. but ash deposits from this eruption can be found to distances of a hundred or more kilometers in all directions except for the quadrant northwest of Long Valley Caldera (Izett et al., 1982).

B. Extent And Thickness Of Ash Deposits

Ash deposits from the northern Mono eruptions of 660 to 620 years ago extend at least 100 km northeast of the vent area and are up to 3 cm thick at this distance (Sieh and Bursik. 1986). Ash thicknesses of 10 cm or more are found within 40 km of the vent area and thickness of 1 meter or more are found only within 10 km of the vent area.

The most voluminous (0.15 km^3) airfall deposit from the most recent Inyo eruptions extends about 190 km to the south. Ash deposits of 10 cm or more thick are found up to 20 or 30 km from the vent. while ash of 1 meter or more in thickness is restricted to an area within 10 km of the vent. Ash deposits from the less voluminous eruptions of the most recent Inyo eruptive episode extend no further than 25 km from the vent area (Miller, 1985).

Ash deposits from the Bishop Tuff eruption have been found as far as 1700 km to the east in central Kansas (Izett et al., 1982). Ash fall deposits from this eruption are as much as 1 meter thick at a distance of 120 km from the vent, 40 cm thick at 200 km distance, and 15 cm thick at a distance of 500 km (Miller, 1982).

By comparing ash deposits from past volcanic eruptions involving up to 1 km^3 of erupted material, Miller (1982) estimated that an eruption of 1 km^3 of pyroclastic material could potentially deposit 20 cm of ash at 35 km distance, 5 cm of ash at 85 km distance, and 1 cm of ash at 300 km distance.

VI. APPLICATIONS TO THE YUCCA MOUNTAIN SITE

A. Probability Of Eruptions

1. Eruptions Of Very Large Volume. A recurrence of a Bishop Tuff-type eruption in the western Great Basin, involving several hundred cubic kilometers of erupted material, would pose the greatest hazard to the Yucca Mountain site during the preclosure period. Such an eruption could deposit 1 meter or more of ash at the Yucca Mountain site, depending on the distance of the eruption site and wind conditions at the time of eruption. The probability of such an eruption occurring during the preclosure period, however, is considered extremely low to non-existent. No eruption of such magnitude has occurred on Earth during historic time. Two eruptions of this magnitude have occurred in the western United States in the past 1 m.y. (Bishop Tuff eruption at 0.7 m.y. and Lava Creek Tuff eruption, Yellowstone, Wyoming, at 0.6 m.y.). **2. Eruptions Of Small Volume (<1Km^3).** Eruption of small volume rhyolite domes, all presumably having some associated pyroclastic activity, has taken place at least 48 times within the last 100,000 years in the Coso and Long Valley volcanic areas. In the last 10,000 years, at least 28 small volume rhyolitic eruptions have occurred in the Mono and Inyo chains of the Long Valley volcanic area. The most recent eruptive episode of the Mono and Inyo chains at 650 to 550 years ago produced 8 new domes and flows and at least 12 separate airfall plumes. The repeated recurrence of these small volume rhyolite eruptions in the western Great Basin indicate that eruptions of this type [illegible] most likely volcanic event to occur during the preclosure period.

B. Potential Ash Fall At Yucca Mountain

The amount of ash that would accumulate at the Yucca Mountain site from a silicic eruption in the western Great Basin depends on the volume of ash erupted, the distance to the vent location, and wind direction at the time of eruption. The largest known volume of ash erupted in a single eruptive episode in the western Great Basin during the last 100,000 years is 0.42 km^3 from the northern Mono chain about 650 years ago (Sieh and Bursik, 1986). An eruption involving 1 km^3 of ash is therefore considered to be the most voluminous that could be reasonably expected during the preclosure period. The most likely area for such an eruption to occur would be the Mono-Inyo area or the Coso area. The thickness versus distance curve estimated by Miller (1982) shows that ash from a 1 km^3 eruption in the Mono-Inyo area (250 km distance) would deposit about 1 cm of ash at the Yucca Mountain site. The same eruption in the Coso field (150 km distance) would deposit 2 to 3 cm of ash at the Yucca Mountain site. These estimates can be considered "worst-case", because they assume both a maximum reasonable volume of erupted ash and that the Yucca Mountain site would lie directly on the dispersal axis of the ash fall plume. An "average" eruption would involve less than 0.5 km^3 of ash, in which case the thickness of ash deposited at the Yucca Mountain site from any volcanic center more than 100 km away would probably be < 1 cm, posing only a minimal hazard to repository facilities.

VII. CONCLUSIONS

A review of Quaternary volcanism both near and distal to the Yucca Mountain area indicates that the only likely volcanic effects at a repository during the preclosure period would be caused by a silicic eruption of small volume (<1 km^3) in the western Great Basin. Hazards from basaltic volcanism in the Yucca Mountain area or from a large volume silicic eruption are considered negligible. A small volume silicic eruption during the preclosure period would probably occur in either the Long Valley or Coso area and could deposit up to 1 cm of ash in the Yucca Mountain area.

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