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United States Department of the Interior

U. S. GEOLOGICAL SURVEY

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Denver Federal Center
Denver, Colorado 80225

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Nuclear Waste Technical Review Board
1100 Wilson Boulevard, Suite 910
Arlington, VA 22209

Dear Sirs,

Attached is a letter report on the subject of long-term passive ventilation, that has been developed in response to conversations with a few of the Board members. The report is not meant to be an exhaustive treatment of the subject, but rather a means of opening a dialogue on the subject. The main points of the report are: 1) ventilation may be a cost effective way of eliminating seepage, and 2) there are abundant natural analogues that could be used to demonstrate the long-term effectiveness of passive ventilation.

Sincerely yours,

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A Case for Long-Term Passive Ventilation of the Proposed Repository at Yucca Mountain, Nevada - Evidence from Natural Analogues

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At the NWTRB May 7th and 8th meeting of 2002, the board heard presentations from Drs. Montazer and Danko on the benefits of long-term passive ventilation of the proposed repository at Yucca Mountain. The U.S. Geological Survey has long advocated ventilation of any mined geologic repository for high-level radioactive waste within the unsaturated zone (Roseboom, 1983), partly because the removal of heat would keep the temperature closer to ambient conditions. These conditions are the most readily studied and best understood. In addition, ventilation has the potential of removing large quantities of water, which would otherwise be available to degrade waste packages and mobilize radioactive waste. For example, the forced air ventilation in the currently proposed designs (both ‘hot’ and ‘cold’) would have the capacity of removing more than 3 orders of magnitude more water than the amount that infiltrates the 3 by 5 km block of Yucca Mountain. Natural ventilation can never attain the level of efficiency of water removal of forced ventilation, but it can enhance the performance of geologic isolation of radioactive waste.

Ventilation in mines and man-made underground openings is well understood, and the engineering application to the proposed repository during the pre-closure period have been described in project documents. This report will focus on natural analogues and the types of effects that could be attained during the post closure period. The examples given are meant to be representative and not as an exhaustive treatment of the subject.

Natural ventilation has been studied and characterized in literally hundreds of caves throughout the world. Air circulation is driven by two general mechanisms: changes in barometric pressure and temperature differentials. Wind Cave in South Dakota provides an end-member case for barometrically controlled air circulation as illustrated in figure 1. In this example, the cave has only one opening, a large volume, and a tight cap rock that isolates the cave from the atmosphere. The passage of a high-pressure system “pumps” the cave full of air. Conversely, the passage of a low-pressure system allows the stored air to exhaust. The small area of the entrance combined with the barometric pumping results in air velocities of up to 35 mph (56 km/hr).

There are two end members of temperature driven air ventilation systems. Carlsbad Caverns, New Mexico has a single entrance and, therefore, responds to barometric pressure change in a manner similar to that of Wind Cave, but its geometric layout is dominantly vertical (figure 2), and thus air exchange is governed by temperature. In the winter, cold outside air sinks into the cave displacing the warmer moister cave air. This is best illustrated by the much lower radon content within the cave during the winter relative to summer (Wilkening and Watkins, 1976; Yarborough, 1980). Figure

3 illustrates this phenomenon over an 11 year period at Szemlo-Hegy, Hungary (Hakl et al., 1997).

The other end-member of a temperature driven system is approximated by Mammoth Cave in Kentucky (figure 4). Here entrances are at different elevations, which allows for a reversal of air circulation depending on the season. In the summer, the relatively cooler air in the cave flows out the lower opening and warm air is drawn in through the upper opening and cooled. During the winter, the relatively warm, moist air is lost from the upper opening and cooler air is drawn in through the lower opening. The velocity of airflow is proportional to the temperature difference between the air outside and inside the cave. Studies at Mammoth Cave also illustrate the importance of the area of openings. The removal of a gate and stone wall at the upper entrance in 1991 caused such an increase in winter airflow that radon levels in the cave decreased by a factor of nine (Olsen, 1996). There was also a relative dry-out and decrease in mean temperature much further into the cave than had existed previously.

Przylibski (1998) studied radon distribution in two caves in Poland. Niedzwiedzia Cave is largely isolated from the atmosphere by air gates. Nonetheless, the radon concentrations vary with outside temperature much as described at Carlsbad Caverns. Radon was measured at seven locations within the cave and at the floor, ceiling and a mid point at each location. The results show a slight tendency for increased radon concentration near the floor of the cave and a more pronounced increase away from the entrance. Thus, “as a rule, locations further from the entrance have poorer ventilation and higher radon concentrations” (Przylibski, 1998, p. 81).

Lechuguilla Cave, within the Carlsbad Caverns National Park, has over 160 km of passageways (<http://www.nps.gov/cave/lech.htm>) and an overall depth of 477 m (Cunningham and LaRock, 1991). Most passages are at an average depth of 244 m below the entrance and over 1.6 km away from the entrance. Sampling at 48 locations within the cave showed little correlation between air circulation (as indicated by radon concentrations) and outside air temperature or barometric pressure changes except near the entrance of the cave. This was observed even though the passage of a low pressure system during a sampling period caused a 0.16 km/hr air flow out of the cave during one sampling period and a high pressure system cause an airflow into the cave of 40 km/hr during another sampling period. Some air mixing within the cave was attributed to elevation differences within the cave, but commonly the deeper, more remote reaches of the cave were fairly stagnant. Four exceptions were found where fresh air (as indicated by temperature, Rn, and CO₂ concentrations) suggested connection to the surface where none are known. These could represent a deep fracture flow system.

Kartchner Caverns, Arizona provides an example of a cave with only one known opening, but which must have communication with the surface by fracture systems as shown in figure 5. The airflow is similar to that at Mammoth. During the winter, warm moist air is lost to the surface by an upper opening, even though none is known.

This cave is very shallow and it is cut by more than 60 mapped faults in a block of ground that is only about 5500 by 3600 m (Jagnow, 1999, p. 49 and fig. 3). Thus, connections to the surface through which air can flow are to be expected. Unlike Mammoth, the velocity of airflow does not seem to be proportional to temperature differences. This is probably due to the greater resistance to air movement provided by the fracture system relative to that provided by large openings. This difference also explains the tendency for the cave to be more responsive to pressure changes than to temperature changes during the summer months.

Air flow in caves is not generally large enough to decrease the relative humidity below 99 percent, and in fact, there is a conscious effort in 'show caves' to keep air flow at a minimum in order to prevent dry out of the caves and the concomitant cessation of speleothem formation. Several caves, especially ones where the size of the natural opening has been expanded to accommodate tourists, have a system of doors that prevents large volumes of air exchange. At Kartchner Caverns, which does have an air lock system, the average moisture lost from the cave by evaporation is estimated (Buecher, 1999) to be 21,000 gal/yr (92,500 l/yr) for a block of ground that is only about 3,600 by 5,500 m.

The Science and Engineering Report (DOE, 2001) documents the possible effectiveness of passive ventilation. A scenario is presented in which the relative humidity remains below 40 percent for 10,000 years (figure 6), even though infiltration is modeled at more than 10 times the current rate.

Yucca Mountain provides a self analogue for passive ventilation and water removal. Wells UZ6 and UZ6S, both drilled near Yucca Crest, exhibit constant airflow. Well UZ6 is drilled into the top of the Topopah Spring Tuff and has only surface casing. Well UZ6S is drilled through the Topopah Spring Tuff and is cased through the Tiva Canyon Tuff. In the winter, both wells exhaust air that is at near constant temperature and saturated with water vapor (Weeks, 1987). The total water lost from the two wells is about 650 l/d. The airflow occurs because the air in the well is warmer and moister and therefore less dense than the atmospheric air. The latter is presumably drawn in through the fractured Topopah Spring Tuff where it crops out in Solitario Canyon. Direction of airflow during the summer is erratic, and as with Kartchner Caverns barometric effects are much more important.

Figure 7 presents a schematic plan view and cross section of a proposed repository at Yucca Mountain. The geohydrologic system of the mountain is favorable for a passive ventilation system similar to the naturally occurring one at Kartchner Caverns even after the access tunnels and ventilation shafts have been sealed. The welded Tiva Canyon Tuff has a very high air permeability (about 100 darcies), and therefore, residence time for air ranges from 1.6 to 3.0 yrs with a mean value of 2.5 years (Weeks and Thorstenson, 2001). The PTn has a much lower permeability, and where wet, is nearly impermeable to the flow of air. The welded Topopah Spring Tuff is hydrologically similar to the welded Tiva Canyon Tuff. Studies of carbon isotopes and chlorofluorocarbons (CFCs) in air from the unsaturated zone show that air circulation is rapid to the base of the Tiva Canyon

Tuff, but that the Topopah Spring Tuff is at least partly isolated from the atmosphere except where it is connected to the surface by boreholes or outcrop (Thorstenson et al., 1998).

The ECRB has a pneumatic connection to the surface by way of the Solitario Canyon fault and outcrops of fractured Topopah Spring Tuff. These pathways may explain the airflow out of the first bulkhead during the passage of a low pressure system (barometric pumping). Unfortunately, after sealing of the repository, this pumping might only ventilate the western side of a proposed repository in a manner analogous to that seen in single entrance caves. If the PTn is brecciated by the Ghost Dance fault, then extending drifts from the perimeter drift into the fault zone might create a natural ventilation flow from the lower eastern side through the repository and out the higher western side with the flow being strongly augmented by heat from the radioactive waste. If the PTn is not brecciated by faulting, or north of the region of known offset, raises could be driven to the base of the welded Tiva Canyon Tuff. Because neither the raises nor the western perimeter drift would reach the surface, there would be no preferential path for human intrusion. Seal at the ends of the emplacement drifts would have to allow air circulation, but prevent leaked radiation, but one can readily envision ways in which this could be done.

There may be considerable benefit to the project if the feasibility and benefits of longterm passive ventilation is investigated. This is especially true with respect to the impact on UZ hydrology. The dry-out period may be extended and the seepage flux likely would be decreased or even totally abated.

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FIGURES



Figure 1. Wind Cave, South Dakota, has a small single opening circulation is controlled by barometric pressure changes. Wind can reach 35 mph with large pressure changes.



Figure 2. Carlsbad, New Mexico is a single opening cave, and subject to pressure circulation, but air turnover is very seasonal. Cold winter air (blue) sinks into the cave and displaces warm moist air (red).

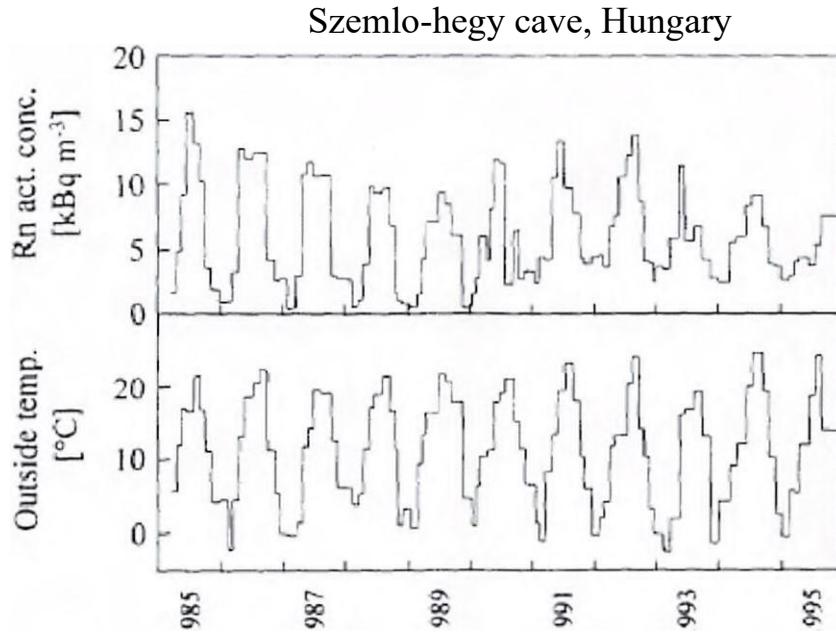


Figure 3. Radon concentrations in kilo becquerel per liter as a function of time in Szemlo-hegy cave. Hungary (from Hakl et al., 1997, Fig. 4).

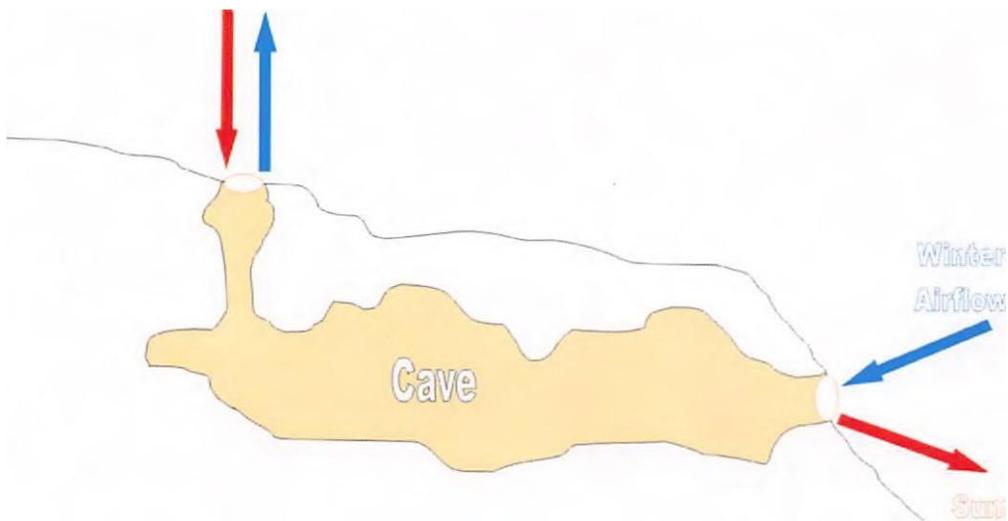


Figure 4. Caves like Mammoth, Kentucky have multiple openings, and air circulation is driven by temperature differences.

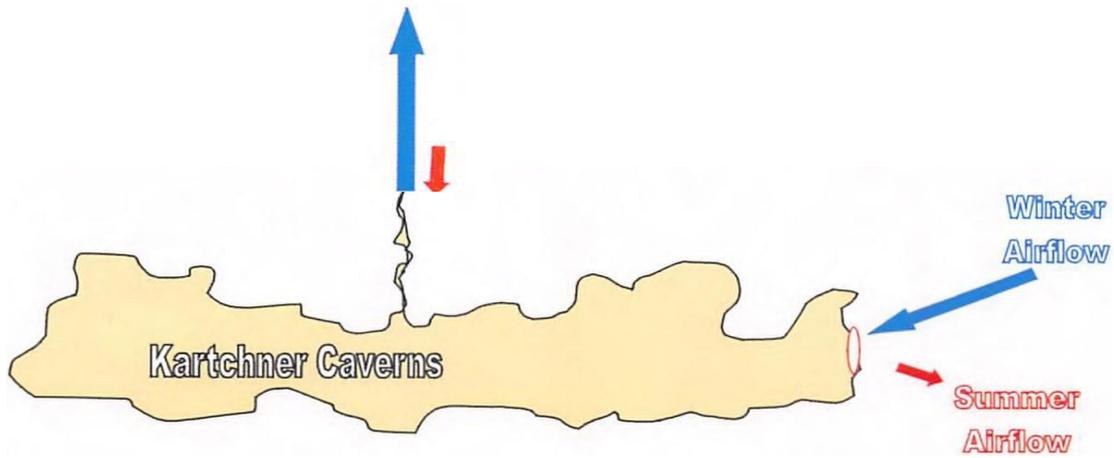


Figure 5. Kartchner Caverns is apparently a single opening cave, but the high degree of fracturing causes circulation to be like that of a cave with openings at different elevations.

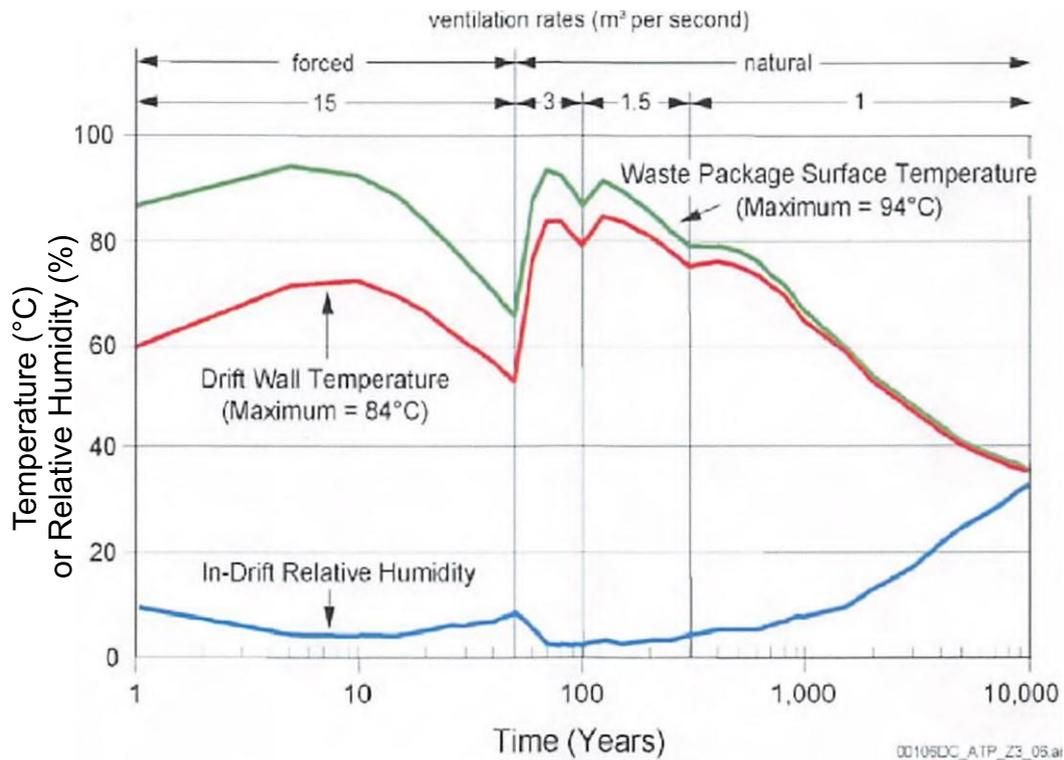


Figure 6 Plot showing in-drift temperature and relative humidity as a function of time and at various ventilation rates (from DOE. 2001. fig 2-15)

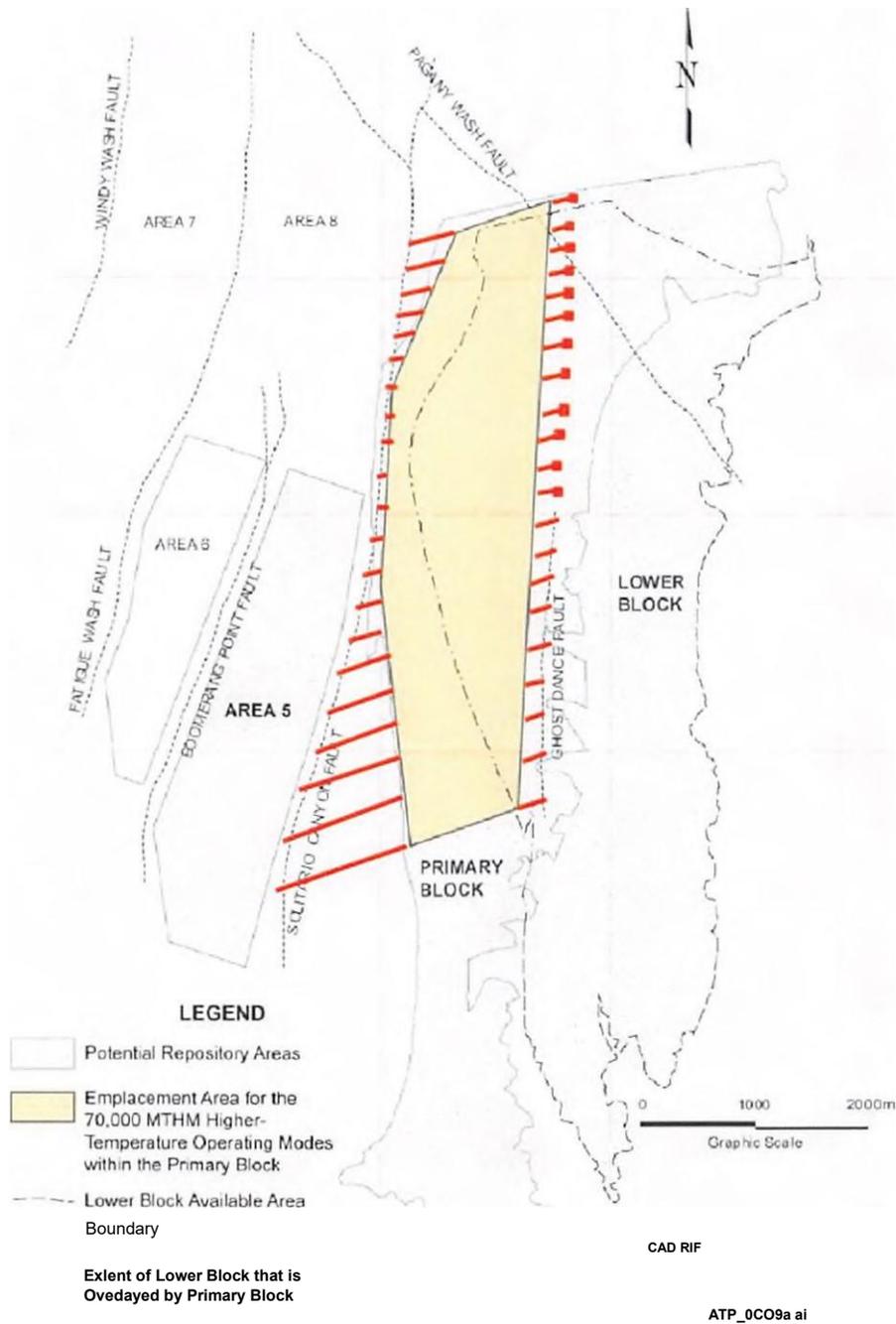
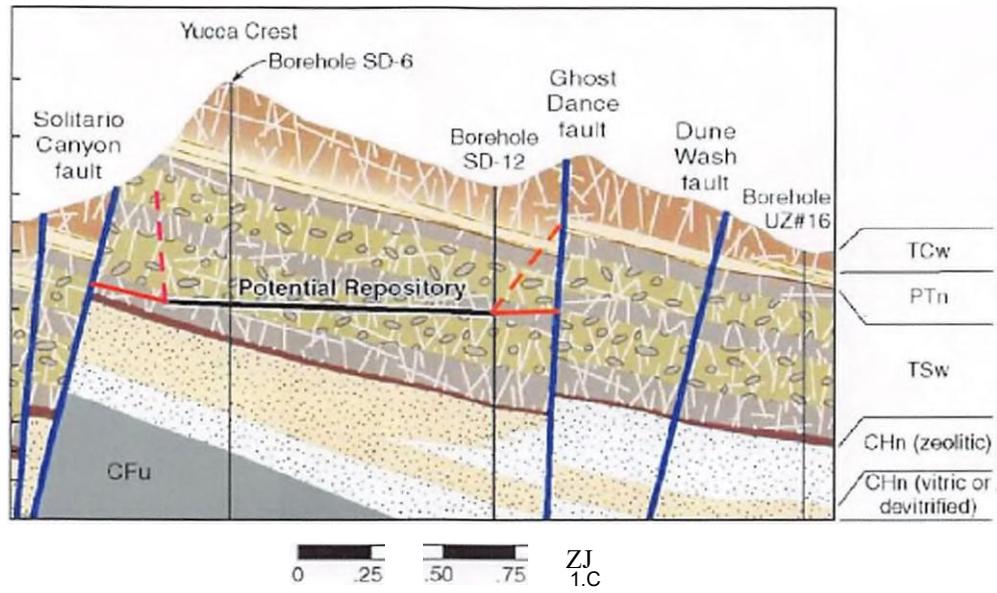


Figure 7a Schematic plan view of the potential repository showing ventilation drifts (in red) that terminate in faults of raises that extend to the base of the welded Tiva Canyon Tuff (after DOE, 2001, fig. 2-5).



(b)

Figure 7b Schematic cross section of Yucca Mountain showing the hydrogeologic units, principle faults, the potential repository, and possible augmentations to passive ventilation (red lines)