SALT REPOSITORY UNDERGROUND WASTE HANDLING DESIGN CONSIDERATIONS

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ABSTRACT

This paper discusses the lessons learned during the design, operational planning, and early startup phases of underground waste handling operations at WIPP. The unique nature of planning and conducting a transuranic waste disposal operation in a deep geologic salt formation offers many unusual circumstances to equipment and operating personnel. Normal nuclear considerations such as limiting personnel radiation exposures, handling large and heavy shielding casks, and conducting precise operational sequences are impacted by the new working environment of the mine. Some aspects of these additional design considerations are discussed.

INTRODUCTION

Design work and site underground development activities, necessary for receipt of contact-handled and remote-handled transuranic waste at the the Waste Isolation Pilot Plant (WIPP) are approximately 95% complete. Actual nuclear waste handling operations are scheduled to begin in October 1988. Activities currently taking place include training operating technicians, checking out completed facilities, and proving waste handling equipment and techniques (1,2). The design activities, operational planning activities, and experience in developing the underground storage horizon have offered learning experience obtained during the development and operation of the WIPP mine and waste handling equipment. Some of the observations seem elementary, but have proven to be easily forgotten during the rigor of developing a future repository site. It is hoped that the information will aid future repository design efforts. be easily forgotten during the rigor of developing a future repository site. It is hoped that the information will aid future repository design efforts.

Compromises Between Mining and Nuclear Technology

The design of a repository involves the unique combination of two vastly different technologies. These are nuclear engineering and mining engineering technologies. The nuclear engineer is not normally confronted with working in an environment with crude floor surfaces, limited space envelopes, limited ventilation, and changing work space envelopes. The mining engineer is not accustomed to high precision mining tolerances, handling the very highly concentrated loads associated with nuclear shielding casks, working with radioactive sources, and the environmental monitoring associated with a nuclear activity. During the design process, interaction between the two disciplines is crucial to a successful repository operation.

Compromises are necessary from each industry's accustomed standards to obtain a workable solution to everyday operational requirements. For example, the WIPP finds it necessary to impose criteria for underground roadway roughness. This need, from the nuclear designer side, arises due to the large weight, size, and unusual wheel loadings posed by equipment. Mining engineers are forced to consider the ability of available equipment to produce the desired road surfaces, and the resulting expense and time required to meet necessary floor roughness criteria. The floor roughness criteria for WIPP are set at acceptable deviations of no more than 5.1 cm in 6.1 m and no more than 2.5 cm in 0.6 m. These criteria were determined by surveying existing drifts, to determine what could be achieved with existing equipment at the time of the criteria specification, and then by determining if the criteria were acceptable to available waste handling equipment designs. This roughness specification represents more stringent criteria for floor surfaces than normally imposed on mine floors, and yet is far from the criteria for normal concrete surfaces found in nuclear facilities. The established criteria forced the mining engineers to plan to smooth the as-cut floor by both filling and reconstituting floors, and to purchase a machine capable of planing the high spots of the floors. Waste handling equipment required use of pneumatic tires, where possible, in preference to solid tires, to better negotiate the rough underground roads. In these ways both the mining criteria and equipment were compromised to come to a reasonable working solution.

Maximum longitudinal slopes in the mine travelways and emplacement rooms are established at 6 percent and 3 percent, respectively. The 6 percent was established due to the fact that grades of this magnitude already existed when waste handling equipment specification began, and to change these grades would be a major task. Design experience has shown that it is preferable to keep travelway grades as low as possible, since this affects the power and traction design of all equipment. The WIPP acceptable room slope criterion of 3 percent is based on available records of natural slope of the sedimentary formation. It is standard practice, in the storage horizon of WIPP, to follow the stratigraphy so that the back (ceiling) elevation is 1.2-1.5 m (4-5 feet) from the nearest clay seam or other weak rock junctions. Otherwise, rock bolting is required to assure a stable back.

When specifying requirements for underground equipment, it is important to give realistic or representative values to criteria such as maximum grades, equipment rolling resistance, and traction coefficients. WIPP uses the following values for most waste handling equipment:

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Maximum grade: 6%
Traction coefficient: 0.25
Rolling resistance: 8%

These numbers represent the worst cases found in WIPP, which are loose-salt areas. Specifying lesser parameters may result in equipment that is underpowered or that gets stuck easily in loose-salt areas.

The salt in the WIPP deep geologic site exhibits the property called creep closure, which is a plastic-like closure behavior due to the lithostatic pressure imposed by the salt formation. This gradual closure phenomenon is a positive feature for the use of salt as a repository medium, since the salt will eventually encase buried waste, and the waste will become integral with the salt at the natural lithostatic pressure of 14,800 kPa (2150 psi). This fact, once explained, has proven to be a comfort to concerned citizens.

The creep closure property represents a major design consideration to the repository mine and equipment designers. The WIPP salt is slowly and steadily closing at an approximate rate of 5-8 cm per year, with a lithostatic pressure (14,800 kPa) representing an almost irresistible force to anything standing in the closure way. The following major items are addressed in the mine design and development:

- Waste storage rooms and access drifts are sized to allow for creep closure, until the area use is complete or until scheduled drift maintenance will occur.
- Emplacement rooms are mined only slightly ahead of expected use time, to minimize the amount of creep closure experienced before beginning emplacement operations.
- Crews and equipment are identified to maintain roadway surfaces and acceptable drift size for operations.
- Structures, such as ventilation bulkheads, are designed to flex or move as the drifts gradually close.

Drift and emplacement room closure is not expected to cause catastrophic failure of the salt "beams" that comprise the roofs and floors of the underground openings, because the closure occurs very gradually over a prolonged period of time. The ability of the salt to flow (or move somewhat plasticly) prevents the buildup of stress concentrations that could cause sudden failure of the stress-bearing salt members. Sloughing or spalling of small slabs of salt occurs in the ribs (walls), back (ceiling), and floor. This sloughing occurs particularly at the corners of the openings where the ribs meet the back and floor. The mine drifts are continually inspected for loose rock sections in the drifts. Loose sections are either loosened and removed, or rock bolts are installed in the weak area, to provide the necessary additional support to make the section stable and safe.

Basic Repository Design Considerations

A basic lesson learned at WIPP is that the waste handling methodology and equipment design should be established early, before the mine design is firmly established. Such criteria as drift size, bulkhead size and placement, ventilation requirements, storage room size, intersection size and design are very dependent on handling equipment size and design. As an example of this point, WIPP remote-handled transuranic waste cask handling requires the use of a 41-ton forklift in the underground storage horizon. This forklift is 3.7 m wide, 9.8 m long, 3.2 m high, and, loaded with a cask, weighs approximately 91,000 kg. This machine requires a relatively large amount of room to negotiate turns (the outside turning radius is 7.6 m) and maneuver in emplacement rooms. It also has a large 10-cylinder diesel engine that requires 566 cubic meters per minute (20,000 cubic feet per minute) of ventilation air to maintain an atmosphere acceptable for workers. This piece of equipment, by itself and in conjunction with other equipment, drives many of the underground design requirements listed above.

WIPP is currently considering a fourth shaft, to provide a ventilation capacity greater than the present 5,950 cubic meters per minute (210,000 cubic feet per minute). The proposed additional shaft will give WIPP an underground ventilation capacity of 11,600 cubic meters per minute (410,000 cubic feet per minute). This need was recognized when all ventilation requirements were available and calculated. Without the installation of an additional ventilation shaft, WIPP will limit, carefully monitor, and control concurrent activities involving use of diesel-operated equipment, due to the air ventilation requirements of that equipment. All equipment and processes to be run concurrently must be established early in the design stage, to adequately size the supply and exhaust shafts and ventilation equipment.

Mine ventilation requirements are dominated by the diesel equipment to be operated in the underground horizon. It is desirable to specify electrically operated equipment, whenever practical, to minimize ventilation requirements. This electrical equipment may be driven either by rechargeable battery systems or electrical cable connection. Equipment having limited mobility requirements can use electrical cable connections. WIPP equipment--such as portable fans, portable breathing air compressors, a large portable high efficiency particulate air (HEPA) vacuum system, and the large 470-horsepower continuous miner used to excavate the underground drifts--all use electrical cable connection to provide power to their electrical motors. Factors that often disallow the use of battery-driven vehicles are long duty cycles and large horsepower requirements of the equipment. WIPP has personnel transporters, small forklifts, and portable personnel lifts as examples of battery-powered equipment.

WIPP ventilation engineers have also found it extremely desirable to have automated real-time monitoring and control for the underground ventilation air. The factors monitored and controlled are air quality and quantity in any given area. This ability is particularly important if ventilation air is only marginal in quantity to meet process needs. If the ventilation supply is somewhat in excess of requirements, control and monitoring functions are less critical, but still important.

Much of the WIPP drift sizing is based on equipment turning and maneuvering needs. The design process is an iterative process between equipment and mine design considerations, since mine stability and maintenance requirements must be considered. The most restrictive drift intersection used by waste handling equipment at WIPP is nominally 7.6 m x 6.1 m with a 3.7 m height. All intersection corners are chamfered (rather than 90-degree angles) at least 1.2 m in each direction. This chamfering of the corners accomplishes two important functions: 1) it relieves the stress concentration point that naturally occurs at such a sharp edge; and 2) it makes equipment turning, in the intersection, easier.

When specifying drift sizes, it is necessary to recall the difference between nominal drift size and actual working envelope available for equipment maneuvering operations. Two things can reduce the effective drift size from the nominal size: 1) creep closure; and 2) placement of utility lines and ducts. WIPP equipment engineers generally reduce the nominal drift size by at least 0.5 m (1.5 feet) in both the horizontal and vertical directions as an allowance for creep, rock bolts, lighting, and other minimal obstructions. Placement of utility lines and ducts must be carefully planned to avoid interfering with needed equipment travel envelopes. WIPP has been forced to move electrical lines and ducting when this consideration was neglected.

A problem that has occurred at WIPP is that a nominal size 4.3 m (14 ft.) wide bulkhead door may have a usable width of only 4.1 m, due to the way the hinges and doors are hung. Doors should be hung so the usable opening of the door is not lessened by the door and hinges. Bulkhead and all facility door widths and heights should be specified as actual clear openings (not nominal size openings), so there is no mistaking the clear, usable opening available.

In the early design stages of WIPP, equipment such as the large forklift dominated bulkhead size and placement. Bulkheads must be wide enough to allow the equipment to pass easily. A minimum of 0.3 m of clearance on each side of the machine or carried load is suggested. Bulkheads should be located a sufficient distance from the intersections to avoid affecting equipment turning ability. The effective drift width is reduced, for turning purposes, if the bulkhead is located too close to the intersection. A vehicle cannot swing wide to make a turn if the bulkhead doorway is close to the intersection. In the case of a forklift, the door position may prevent the ability to swing the tail end of the machine as it turns on its front wheels (forklifts are rear wheel steered).

Radiological Design Considerations

WIPP engineers learned that it is important to do a radiation dose assessment for waste handling operations, early in the equipment and facility design process. Design-objective personnel exposure limits, imposed by regulatory rules for this type of operation, are generally limited to 0.01 Sv/man/yr (1000 mrem/man/yr) (3). Based on 250 work days per year, this means that the average operator daily exposure must be 0.04 mSv/day (4.0 mrem/day) or less. High throughput facilities may find it necessary to implement either extremely conservative shielding (which increases equipment size and weight) or to use automated and/or unmanned equipment. Initial WIPP dose estimates show that general radiation background in an area, due to emplaced waste, can represent a major portion of the accumulated exposure. An eight-hour stay in a background radiation field of even 0.005 mSv/hr (0.5 mrem/hr) will consume an operator's allowable average daily radiation exposure. Operator stay time in an emplacement area should be carefully controlled both during and after waste emplacement operations.

The virgin salt (2.15 g/cm^3) represents a reasonably effective shielding material for gamma activity. Large canisters having gamma surface dose rates of 100 Sv/hr (10,000 Rem/hr) are shielded to less than 0.05 mSv/hr (5 mrem/hr) by 1 meter of salt. However, waste forms with significant neutron activity represent a larger shielding problem, since salt is not as effective in neutron shielding as for gamma shielding. Attenuation coefficients of 0.032 cm^{-1} and 0.108 cm^{-1} were calculated for neutron and gamma radiation, (Ref. 4) respectively, in virgin salt with a density of 2.2 g/cm^3. Thus, the tenth-value thickness of virgin salt is 8.4 cm for gamma activity and 28.3 cm for neutron activity. The operator radiation dose from gamma activity and neutron activity is additive, so the designer must consider both kinds of radiation in dose assessments. The WIPP found that Savannah River borosilicate glass canisters have potential 3-4 mSv/hr (300-400 mrem/hr) neutron surface dose rates caused primarily by alpha-neutron reactions in the waste matrix (5).

Contamination Control and Decontamination

The WIPP is designed with instrumentation in the exhaust shaft to detect any airborne radioactive contamination in the mine exhaust air. If the instruments detect contamination in the exhaust air stream, the air stream is diverted to a high efficiency particulate air (HEPA) filter bank, and two of the three exhaust fans are shut down, reducing mine ventilation from 6,000 to 2,000 cubic meters per minute. At this point, the source of the contamination must be identified and brought under control, before normal underground operations can resume.

A mine environment, with its rough, porous, and loose surfaces, represents a potentially difficult decontamination task. WIPP has procured a high capacity (71 cubic meters per minute) HEPA filtered vacuum system, capable of operating a 15.2 cm (six-inch) vacuum hose. This high volume vacuum system will be used to suck up as much loose salt material and contamination as possible, in the event of a sizable contamination spill. Small area decontamination is feasible, for remaining contamination, using conventional scabbing techniques with vacuum and enclosure designs to prevent dust and contamination spread resulting from this operation. Large area decontamination, after vacuuming, could prove to be an extremely time-consuming, if not impossible, task. The interim, or perhaps even final solution might be to spray a peelable-type coating or other coating to both absorb and/or fix remaining contamination after the vacuum operation. Plans are being made at WIPP to investigate and prove this technique, as a contingency plan for accidents.

Recommendations for Future Repositories

The trend of decreasing allowable personnel radiation doses makes it desirable to remove personnel from the immediate vicinity of the waste handling operations. This can be accomplished by incorporating automated or robotic waste handling equipment. Once this step is taken, the option of reducing or eliminating shielding (such as casks) from repository waste handling operations, involving high activity waste, is available. Elimination of shielding from the combination of a cask and canister emplacement equipment combination can amount to a greater than 85 percent weight savings. As an example, the WIPP remote-handling waste cask weighs 67,000 pounds and carries a 10,000 pound (maximum) canister. Waste package handling equipment size can conceivably be reduced from the size required to carry a 77,000-pound load to that required to carry a 10,000-pound load. This would allow the following items to be reduced:

- Surface to underground hoist capacity and shaft size
- Underground transporter and emplacement equipment and size
- Mine drift size
- Mine ventilation capacity requirements

Reduction of the above items can result in lower initial capital outlay, reduced electricity consumption, reduced mining costs, and reduced maintenance costs.

The use of automated processes can reduce the required crew size for waste handling operations and reduce the chance of human error in waste handling operations. This is a significant advantage with the high visibility and scrutiny that nuclear repository operations experience. The reduced direct contact with waste packages reduces personnel risk and potential notable occurrences.

Most repository waste handling operations are basic material handling operations that are similar to standard warehousing operations that are being automated in other industries. The primary engineering difficulties and differences involve the safe recovery from equipment failures, when handling lightly shielded or unshielded waste packages with high radiation fields. Special design features can be developed to allow recovery from the off-normal equipment failures.

CONCLUSIONS

Experience at WIPP has shown that the repository design and operation requires recognition of the characteristics and needs of both the nuclear and mining industries. It is desirable to identify and design all parallel activities and required process equipment, prior to completion of the repository mine final design. Such factors as ventilation requirements, drift sizes, bulkhead sizes and placement, floor roughness criteria, maximum grades, and intersection size design are dependent on these items.

Mine creep closure properties must be factored into the mine and equipment design considerations. The continually closing nature of the salt mine forces design engineers to reduce, for equipment design purpose, the nominal size of the drifts to a working envelope that will be present during the lifetime usage of the equipment. Drift trimming may be required to continue operations if sufficient creep allowance is not provided during initial mining operations. Placement of utility lines and ventilation ducts must also be carefully planned so that required working envelopes in drifts are not violated.

It is important to perform a total radiation dose assessment, for waste handling operations, early in the equipment and facility design process to ensure that personnel radiation dose limits can be met. Under present limits (1,000 mrem/man/year) even background radiation exposures can be a substantial consideration for a continuous full-time operation. Dose assessments must include both gamma and neutron exposure, since these are additive exposures to be included as an operator's accumulated radiation dose. Use of automated or robotic equipment, or very conservative shielding, may be required in a high-throughput repository operation to meet personnel radiation exposure goals.

WIPP is in a start-up mode at the present time. Systems are being built and checked out for proper operation. Actual nuclear waste handling operations will begin in October 1988. Many lessons are being learned in starting the nation's first repository site. Some seem elementary, yet can be easily neglected in the complex process of designing and building the facility. Attention to design details such as door sizes, floor roughness criteria, maximum floor grades, and equipment traction coefficients are important to a successful repository operation.

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