THE DESIGN OF BACKFILLING AND SEALING IN A DEEP REPOSITORY

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ABSTRACT

The criteria of a Deep Repository impose unusual demands on the design of backfills and seals. This paper examines those demands and the options to satisfy them with conventional technology.

INTRODUCTION

The background to this paper is in the work that has been going on for four years to develop the design of a combined ILW/LLW Deep Repository in the UK. Part of that work has involved the consideration of how to backfill and seal the Repository, and this consideration is continuing. This paper presents analyses of the needs, constraints, and options for backfilling and sealing.

Three situations are identified: backfilling the waste stacks within the vaults, backfilling access spaces that do not have waste in them, and sealing the accesses to restrict radionuclide movement from the waste to the biosphere.

BASE INFORMATION

In the Repository taken as the base for this paper, approximately 2.9m m^3 of packaged waste was to be disposed of in a 50-year period: 2.1m m^3 of LLW and 0.8m m^3 of ILW. Both forms of waste would be grouted in thin-walled packages.

The vault and vault area designs were developed for "hard rock" conditions in which the largest practicable cavern was selected as the preferred form of vault - 250m long x 25m span x 35m deep. The vaults were to be at a depth of 500m below ground, reached by mine shafts and a network of tunnels (Fig. 1).

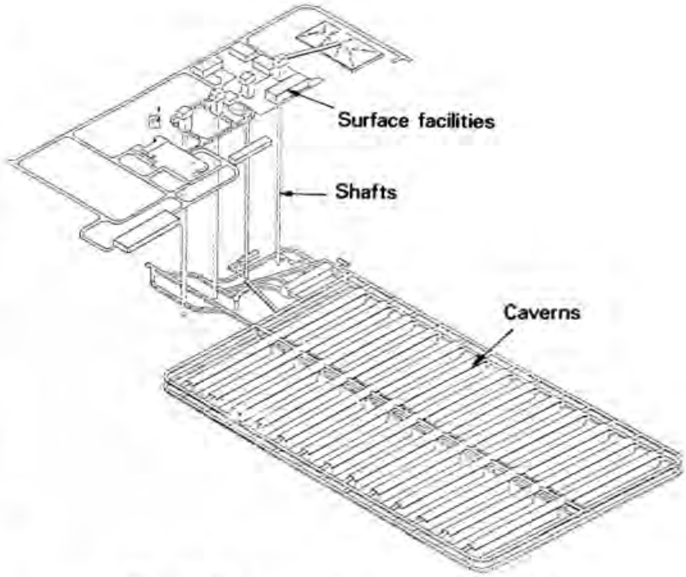

Fig. 1. Deep repository concept design.

The Repository relies on a multi-barrier containment system. In the short term the containment includes the physical contribution of engineered barriers, but in the medium and long terms the important barriers are engineered chemical environments and the natural properties of the host geology.

VAULT BACKFILLING

General Requirements

In order to contribute to the physical barrier, the backfill should have a limited permeability, although very low permeability is not necessarily a good thing as it may allow electrochemical imbalances to build up and promote corrosion.

In order to make its contribution reliable, the backfill should be sufficiently fluid during placement to fill as thoroughly as possible the interstices of the waste stack.

In order to contribute to the chemical barrier, the backfill should have a high (alkaline) pH - cement and lime based materials are alkaline. Sorption is also a desirable property - cement and bentonite are among the materials that offer good sorption.

In order to maintain the waste stack and cavern roof "as designed" for as long as possible, the backfill should solidify with reasonable strength. In order to allow the future option of waste retrieval, the backfill should be less strong than the waste.

All other criteria being satisfied, the backfill should be economical and made from readily available materials.

Intermediate Level Waste

The majority of the ILW was to be packaged and grouted in 500-liter drums and 3 m^3 boxes, both with thin steel walls and unshielded. Individual packages and the waste stack as a whole could not be approached by operators.

The drums and some of the boxes are cylindrical: they therefore pack inefficiently and the volume of backfill may equal or exceed the volume of waste. Rectilinear boxes pack more efficiently, but still need gaps to be backfilled on all faces.

The ILW was to be placed by overhead crane. The ILW stack could therefore rise to the level of the crane rail and was then to be capped with a shielding slab to allow man-access and/or disposal of LLW. The ILW/backfill combination had therefore to be able to support the capping slab and material above.

Low Level Waste

Although the LLW packages were of sufficiently low surface dose rate to be handled and transported unshielded, in the Repository they were to be handled remotely in order to limit dose to operators working constantly with them.

Backfilling therefore would also be remote or using shielding vehicles.

The LLW packages were rectilinear and therefore stacked efficiently but, due to the larger volume, still called for substantial quantities of backfill.

Design of the Backfilling Operation

Practicality in stacking the waste suggests that the waste should be layered and, when a layer is complete, backfill is placed around and over it producing a level surface for the next layer. Economy then suggests that packages of equal height and readily laid out in plan be placed together and partitioned off from packages of a different height so as to control flow of backfill (Fig. 2). The result is a management approach which allocates different areas of the vault(s) in use to different package sizes.

The partitioning depends on the volume of backfill placed in any one operation. The smaller the pour, the less the demand on the plant but the greater the number of partitions. As each partition would be a wall 22m long and 24m high, there is an incentive to make the pours as large as possible. It was considered reasonable to take a maximum pour of $500m^3$ in one long shift using twin mixer/pump sets of capacity $50m^3$/hr each - commercially available plant. If the partitions are built at 25m spacing along the vault, one layer of waste needs $300m^3$ - $500m^3$ backfill depending on package height and efficiency of packing in plan.

Segregation of activities in the Repository meant that the pumps would only get to one end of each cavern, so a pipe run of up to 250m would be needed within the cavern. Such a length means that a fluid and slow-setting mix would be needed, with as little tendency to segregate as possible.

It is also important to recognize that, with no man access allowed in the ILW caverns, all the joints, junctions, and valves in the cavern must be very reliable. It may be necessary to provide the facility to withdraw all the in-cavern components (under radiological control) for frequent cleaning and maintenance to minimize the risk of breakdown.

An alternative to pumping, possibly less open to breakdown, is the use of a skip craned to and from. The cyclic rate of skip movements is so slow in a large cavern, however, that a completely different approach would have to be taken to partitioning in order to keep individual backfilling operations to a reasonable duration.

Formulation of the Backfill Mix

The design conditions above provide an interesting task for the mix designer. A valuable precedent in the nuclear industry is the work done by BNFL and UKAEA on ILW encapsulation grouts, bearing in mind that they are designed for delivery into single packages. In the civil engineering industry, recent work on low-cost backfills for mine workings has offered experience on low cost, low strength materials pumped into place in large quantities.

A preliminary review of the candidate materials suggests:

- Cement - clear candidate in terms of high pH, setting into solid matrix, conventional technology;
- Sand - cheap but disruptive in high shear mixers (commonly used for pumped grouts and bentonite), abrasive in pipelines;
- Pulverized Fuel Ash - cheap and beneficial in mixing and pumping;
- Blast Furnace Slag - low heat of hydration and slower setting cement replacement;
- Lime - highly alkaline, promotes pozzolanic action in pfa;
- Bentonite - commonly used to prevent segregation after mixing;
- Chemical Gelling and Retarding Agents - increasingly used to "tailor" mixers, uncertain complexing behavior with important radionuclides.

Sufficient options and precedents exist to support the view at this stage that a pumpable backfill can be produced from conventional materials. Development is a matter of laboratory and larger scale trials.

MASS BACKFILLING

General Requirements

Mass backfilling involves placement of material in spaces with no waste in them - cavern crowns after stacks have been capped, access tunnels, and shafts.

In order to contribute to the physical barrier, the backfill should have a limited permeability. Ideally the (very low) permeability of the host rock should be restored, but it is unlikely to be practical to assure this.

In order to contribute to the chemical barrier, the backfill should have a high pH and sorption properties. If it is possible to determine that the backfill is "upstream" of the waste, then perhaps alkaline buffering would be the priority, whereas if it is "downstream", perhaps sorption would be.

In order to maintain the integrity of the host rock around the vaults for as long as possible, the backfill should solidify with reasonable strength and stiffness. It should fill the space in which it is placed and not allow excessive fissures or voids either when placed or developing with time.

All other criteria being satisfied, the backfill should be economical and made from readily available materials.

Design Approach

Most backfilling of mine workings has a simple objective: to prevent unacceptable surface settlements cheaply. Permeability constraints are unusual and barrier performance is

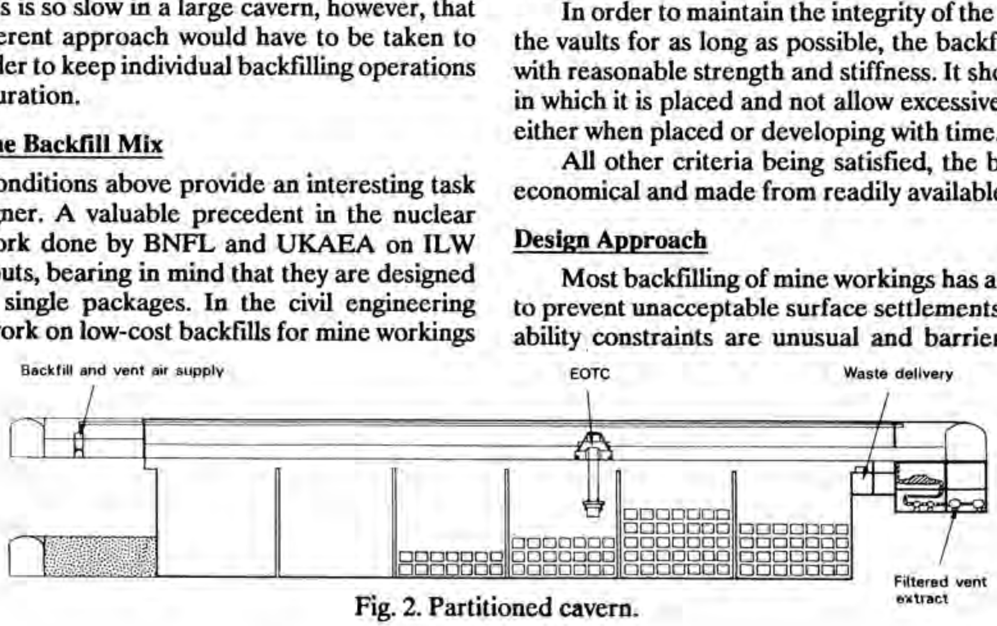

Fig. 2. Partitioned cavern.

irrelevant. It is therefore necessary to assess whether restoration of host rock permeability is absolutely necessary. If it is, conventional (cheap) backfilling will not be acceptable.

Considering only the flow down the tunnel itself, it is simple to demonstrate that, if the backfill permeability is ten times the rock permeability, the tenfold increase in flow can be reduced to threefold by putting in a plug of host rock permeability and one-tenth of the length of the tunnel.

More important, however, is to consider the flow alongside the tunnel. For an 8 meter diameter tunnel, the annulus 2 m thick around it has 25% more cross-sectional area. Taking flow in the tunnel and the annulus together, it is likely that a reasonable and cheap backfill, with intermittent low-permeability plugs, will make little difference to the overall pattern of groundwater flow compared with a total restoration of host rock permeability.

Mining and Civil Engineering Experience

The many and various approaches which have been taken may be summarized:

- Large-scale grouting: relatively shallow workings reached by borehole from the surface; material pumped in (Fig. 3). Good filling can be achieved with adequate venting.
- Mechanically compacted backfill: traditional civil engineering approach, tipping a cement-aggregate mix and compacting it by roller (Fig. 4). Cheap process until headroom limits it.
- Pneumatic stowing: similar to shotcreting in terms of delivery of sand and cement by pneumatic pipe (Fig. 5).
- Pumped concrete: traditional material, most easily controlled by erecting a part-height shutter across the tunnel and progressively withdrawing it (Fig. 6).

In order to fill air pockets along the roof, it will be necessary to fix and withdraw vent pipes; a better result will be achieved with second stage grouting. It will of course be necessary to strip out all services, cabling, etc.

Nuclear Industry Studies

Development work internationally for hard rock repositories has been mainly directed at HLW disposal. Volumes of material are relatively small and the budget relatively generous in view of the technical requirements.

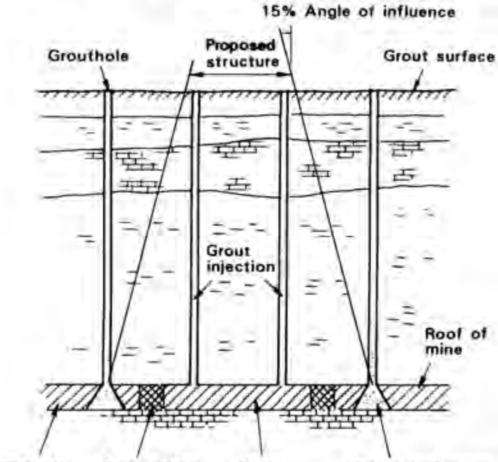

Fig. 3. Grouted backfilling.

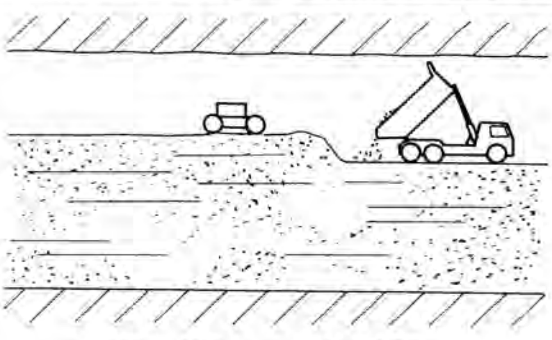

Fig. 4. Compacted backfill.

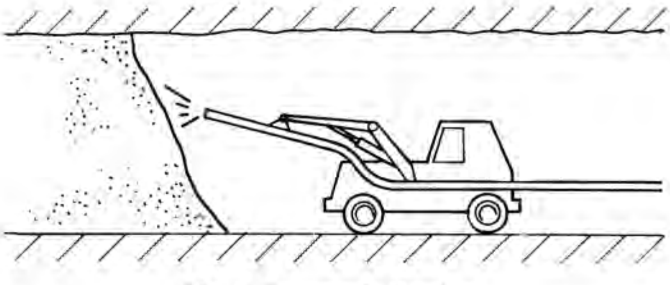

Fig. 5. Pneumatic stowing.

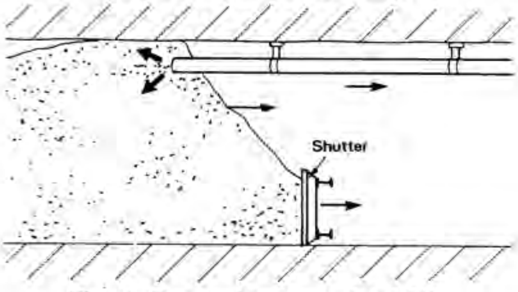

Fig. 6. Pumped concrete backfill.

A preference has been found (1,2) for composites of clay and crushed rock, placed initially by tipping and rolling, and later by pneumatic stowing. Rolled backfill can use an ordinary clay - as in a dam core - but the stowed material is generally formulated with bentonite to produce a matrix in place.

Bentonite block linings to tunnels have been suggested to overcome the problem of closing the interface between the tunnel walls and roof and the backfill.

Placement Operation and Mix Design

The preferences of previous nuclear industry studies may provide the conclusion for the Deep ILW/LLW Repository. However, they are not cheap - particularly when it comes to lining all surfaces with dry bentonite blocks - and a more traditional scheme may be adequate when the long term safety implications are analyzed.

A suggested mass backfilling scheme, to be used with intermittent plugs, would be based on a roller-compacted lean concrete supplemented by pneumatic stowing and poured concrete where access for compaction plant is limited. Perimeter interfaces would be grouted.

PLUGGING AND SEALING

General Requirements

Plugging and sealing are considered primarily as restrictions on groundwater flow. Chemical barrier properties are secondary.

A plug should have a permeability lower than that of the host rock, when all fissures and interfaces are taken into account. Some flexibility is desirable to prevent fracture under long term rock movement.

Sealing is intended to lower the permeability of the host rock where it has been raised by relaxation around excavations and by blasting damage. The lowest viable permeability is probably that of the original host rock.

Design Approach

It is important to take a consistent approach to the design of plugs and seals in order not to allow a bypass flow to negate the plug. Any plug should therefore have an associated sealed zone or "collar" around it in the rock (Fig. 7), and a systematic way of dealing with the plug/rock interface.

If a fault zone of higher permeability intersects the Repository tunnels, this zone may have to be sealed irrespective of plugging the tunnels.

It is assumed that the shafts will be plugged within the stratum of the Repository and any significant low permeability strata above. Shaft plugging within high permeability strata will be ineffective as it will be bypassed in the surrounding rock.

Mining and Civil Engineering Experience

The need to plug an opening and the need to seal a volume of rock, for permanent resistance to groundwater, are conventional demands in mining and civil engineering. In general, however, the needs are for reduction of groundwater flow to an acceptable level: the level which is acceptable through the grout curtain around a dam might not be acceptable in the long term safety case of a Repository.

Conventionally, plugs are made of concrete; the final constituents are determined by the constraints of placement (usually by pumping) and cost. Deficiencies are made good by grouting.

A great deal of experience is available of grouting techniques as the procedure of drilling rock and injecting grout has been standard for many years. Cement is still the commonest base for grouts and both pfa and bentonite are used to improve the delivery properties. More specialized admixtures are used to control setting time, fluidity, and washout and to provide expanding grouts.

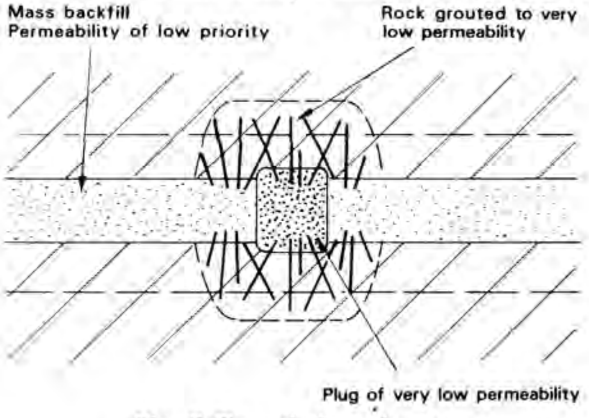

Fig. 7. Tunnel plug scheme.

Chemical grouts are available and are used (for example) to penetrate fissures too narrow for cement grouts. In the circumstances of a Repository, chemical grouts have an insufficiently clear long term benefit and are unlikely to be used. Some caution is also in order when considering admixtures to cement grouts.

Nuclear Industry Studies

The Stripa Project has included trials of tunnel plugging and sealing fault zones (3) which provide both good illustrations of practical technique and direct data. These trials used concrete, bentonite, and cement grouts.

An approach to shaft plugging based on bitumen as the sealing material has also been suggested (4), and could also be applied to tunnels. Bitumen has a long history as a sealant, but being organic it is unwelcome in a Repository.

Plug Design

The design of the plug is largely a sequence definition. The best traditional option is seen to be a concrete block surrounded by dry bentonite lining to the rock on all faces. At the plug position the rock should be carefully cut back to remove any blasting damage and a further collar zone should be grouted to the lowest achievable permeability.

An alternative, more expensive but perhaps more easily verified, would be to construct a complete wall of dry bentonite blocks which would hydrate to close all gaps.

Verification and Quality Assurance

Because of the reliance placed on plugs and sealing, it will be necessary to demonstrate their successful completion. This may be as demanding as the execution, requiring provision to check permeability, to ensure the checking system itself does not diminish the sealing, and to correct any deficiencies.

The best access for working on the rock surrounding a tunnel is the tunnel itself, although some zones may be more conveniently reached from grouting adits, which are also a useful way of working around shafts.

Verification of tunnel backfill and plugs naturally involves some conduits running from the body of the material in place through the plug to the unfilled portion. Steel conduits cast in are perhaps too short-lived; traditionally grouting and pressure test holes can be drilled after casting, and grouted up. A more secure, but expensive, closure could be achieved by placing a "cartridge" of bentonite in the conduit - as has been suggested at Stripa for sealing boreholes (5). This is probably the most attractive way of dealing with the final sealing of plug structures.

CONCLUSIONS

Backfilling and sealing are integral features of the Deep Repository design, from the vaults back to the shafts (Fig. 8).

The vault design and operation needs to incorporate the backfill to arrive at an appropriate stack pattern, operational safety plan, and set of containment barriers.

The backfilling of the remaining spaces needs to be considered in terms of economy, practicality, and the contribution it makes to long term safety.

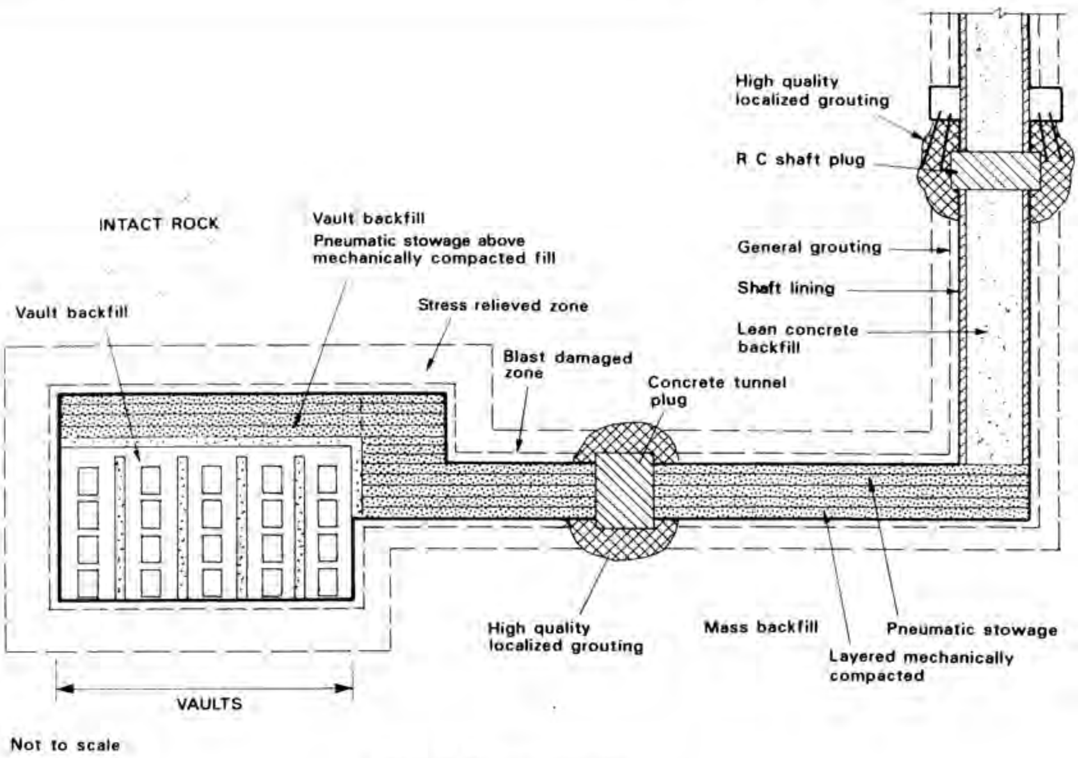

Fig. 8. Repository closure.

Plug and seal systems need to be developed on a consistent basis to achieve reliable control of the groundwater pathway for radionuclide migration.

In each case, the Repository provision will be informed by experience from the mining and civil engineering industries and completed to satisfy the nuclear safety criteria.

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