QUALITATIVE POST-CLOSURE ASSESSMENT OF SHALLOW DISPOSAL FACILITIES

P. Kane, N. Murray, D. Vande Putte
Costain-Arup-Electrowatt Consortium
Electrowatt, Grandford House,
16 Carfax, Horsham, West Sussex,
RH12 1UP, England

ABSTRACT

It is essential to include post-closure safety considerations in repository design. Recognizing the difficulty of carrying out quantitative post-closure assessment in parallel with design, a method was developed to carry out qualitative post-closure assessments. This is based on deriving mathematical expressions for qualitative performance criteria. The present paper describes such a technique, as applied to design selection for shallow repositories at four sites.

THE DESIGN BRIEF

The Costain-Arup-Electrowatt Consortium was awarded a contract in 1986, to prepare concept designs for shallow repositories for UK Nirex Ltd. UK Nirex Ltd is the agency charged with the future disposal of Low and Intermediate Level radioactive wastes in Great Britain. At the time, government policy envisaged the shallow burial of LLW by Nirex, and Nirex had selected four sites which could potentially accommodate a shallow repository. Concept designs, adapted to each site, were required as part of site selection. The designs were to include receipt and treatment facilities as well as disposal vaults under a 5 m cover. Furthermore, for each site, different vault options were to be considered, and an overall preferred design was to be singled out for later detailed design and safety assessment.

As part of the screening of the design the preference was to cover all aspects ie cost, program, operational safety and post-closure performance. Post-closure performance is normally assessed by carrying out safety analyses which include calculations of risk from intrusion and from radionuclide release with groundwater. Such calculations are expensive, time consuming, and require good site characterization. An alternative method for assessing post-closure performance had to be devised because of the tight timescales imposed on the design work and because of the preliminary nature of the site characterization data. The objective was to screen the design concepts using a simple method. This approach dose not rule out the need for comprehensive safety assessment and further development of the design. In fact independently of the design work, preliminary Post-Closure Safety Analysis work was being undertaken by Nirex (1) and further detailed work, taking into account the results of the extensive geological investigations which were being conducted in parallel with the design work, was planned. Subsequent to completing this design work the investigation of the 4 shallow sites was curtailed and Nirex is now evaluating the Deep Geological disposal of low and intermediate level waste.

SITE DESCRIPTIONS

Bradwell

The Bradwell site is on the north tip of the Dengie peninsula, Essex, on the south side of the Blackwater river and mainly east of the existing Bradwell Power Station. With the exception of the power station, the Bradwell area is essentially rural. The site itself rises from 1m Above Ordnance Datum (AOD) in the northeast to 6m AOD in the southwest. The stratum of principal interest for a repository is London Clay, approximately 50m thick. Below the London Clay are the Lower London Tertiaries, a series of thinner and varied strata unlikely to be of advantage in repository construction.

Hydrogeology is reported as dominated by the chalk underlying the Lower London Tertiaries, at about -75m OD. The piezometric head in the clay is expected to be at about OD, and groundwater flow very slowly upwards.

Elstow

The Elstow site is in the Marston Vale, south of Bedford; it is currently referred to as a storage depot. The site area slopes gently to the east from 35m AOD to 30m AOD. The stratum of particular interest, is the Oxford Clay which is approximately 15m thick at the site. Over the Oxford clay lies a weathered material and drift deposits to a combined depth of 2-6m. Below the Oxford Clay are the Kellaways Beds comprising sand up to 3.6m thick and clay about 1.8m thick.

The Kellaways Sand is expected to be a highly permeable stratum with a water table at about 24m AOD or 6-11m below ground level. The water table in the clay (or piezometric head in the sand) implies a limit to depth of open cut or diaphragm wall excavation, below which the clay is in danger of "blowing" up into the excavation.

Fulbeck

The Fulbeck site is in Lincolnshire, 20km southwest of Lincoln. The site is basically flat at about 15m AOD. Drainage is artificial as few ditches cross the site. The site lies on material of the Lower Lias formation, referred to as clay, but appearing as a succession of thin beds of hard clay - verging on soft rock - and limestone of various strengths. The tentative findings of a site investigation were that permeabilities were low and decreased with depth. No stratum of obviously high permeability had been identified.

An upwards flow of groundwater is suggested, but neither piezometric water pressure nor an aquifer is considered to be of major significance to the concept design. The dominant aquifer is believed to be the Sherwood Sandstone, at least 300m below the site.

Killingholme

The Killingholme site is on the south side of the Humber estuary, 5km northwest of Immingham docks. The site comprises relatively flat land, predominantly in agricultural use, and lies at about 10m AOD. The stratum of interest for housing low level waste vaults is the Glacial Till (or Boulder Clay), which is expected to have a thickness of 15 - 20m below the site. While the Till is largely clay of low permeability, it includes lenses and possible beds of higher permeability sand or gravel. The Burnham chalk underlies the Till and may be considered to be an aquifer with a water table at about OD or 8 - 10m below ground level. Piezometric heads have been identified in the sand layers which may be higher than this.

WASTE CHARACTERISTICS

The waste considered for disposal was Low Level, which, in Great Britain means that the total beta-gamma activity is less than 12 GBq/ton and the total alpha activity is below 4 GBq/ton.

Operational wastes were specified to arrive at the repository throughout its 50 year operating life, at the rate of 13 000 m^3 per year. Of this, about 60% would be packaged in 200 liter drums. Drummed wastes would mostly have been conditioned by in-drum compaction or incineration at the producer sites, but would arrive at the repository ungrouted. The remainder, i.e. larger items of waste, would arrive already grouted in 10 to 15 ton steel boxes.

Decommissioning wastes were specified to arrive on site over 50 years at an average of 4000 m^3 per year, in four sizes of steel boxes, ranging from 20 to 110 tons.

THE VAULT DESIGNS AND THEIR ASSESSMENT

It was decided that the Low Level Waste in 200 ℓ drums should be super-compacted and grouted into other containers, to conserve space. Additional benefits arise for post-closure performance as the risk of cap collapse is reduced, the permeability of the vault is reduced, and chemical conditioning by the cement grout is guaranteed for a longer period. Other packages would be disposed of without further treatment.

Nineteen different vault designs were examined and the choice was narrowed down to those shown in Fig. 1. Types 1 and 8 at Elstow and Killingholme were constructed at less depth and covered by a tumulus. The selection process took account of feasibility, geotechnical characteristics, costs, and available land area.

Nirex requested that the team prepare data and statements on aspects of the designs which are expected to impact on long-term radiological performance and to indicate a preferred vault design at each site, based on a series of criteria, which are:

- resistance to water and migration of nuclides with water;
- resistance to intrusion

In examining the criteria, it was noted that these could be further refined, and in many cases, expressed by parameters which can be given numerical values.

Resistance to Groundwater and Migration with Groundwater

The quality of the vault as a physical and chemical barrier to groundwater will depend on a number of parameters.

Flow Projected Area (A′)

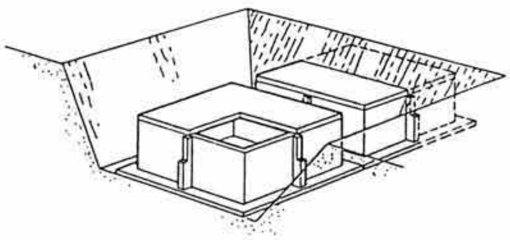
The greater the projected area of the vaults normal to groundwater advective flow lines, the greater the washout from the vault. This projected area will depend on the vault dimensions and local groundwater flow lines. Based on preliminary information available at the time, it was assumed that the flow lines are vertical. Hence A′ will be the total projected area of all the vaults relative to site surface. The smaller this parameter, the better.

Specific Area of the Vaults (A_S)

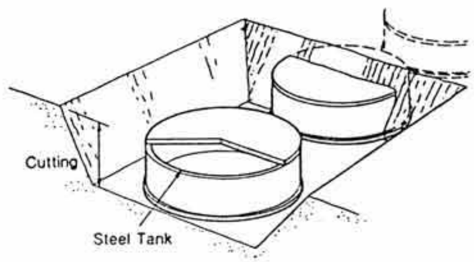
The greater the total surface area of the vaults, the greater the potential for diffusive transport of nuclides from the vault to the surrounding material. One can express this characteristic by the ratio $A_S = A_V/V$, where A_V is the total surface area of the vaults and V is the total volume of waste in the vaults. The smaller this parameter, the better.

Distance From the Vault to the Biosphere (L_P)

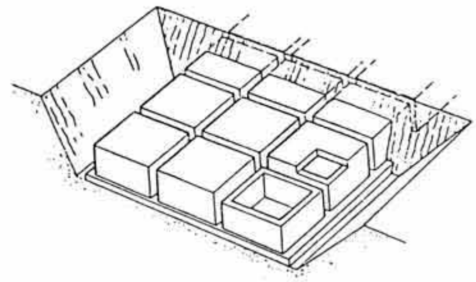
The distance from the center of gravity of the vault to the nearest biosphere receptor is a measure of the radiological protection inherent in the design. This distance (L_P) is the smallest of distances to either the nearest aquifer or to the surface of finished ground. This parameter will depend on the vault design and on site characteristics. In the case



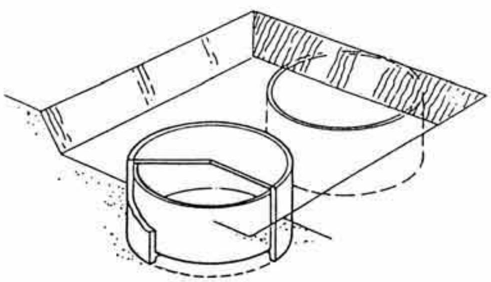
1 SQUARE VAULTS
(Bradwell, Elstow, Fulbeck, Killingholme)



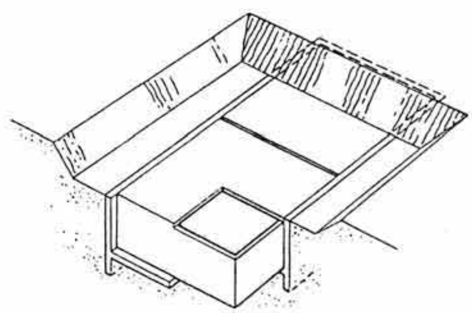
3 CIRCULAR VAULTS
(Killingholme)



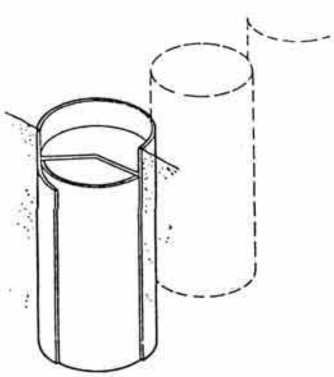
5 EGGBOX
(Elstow)



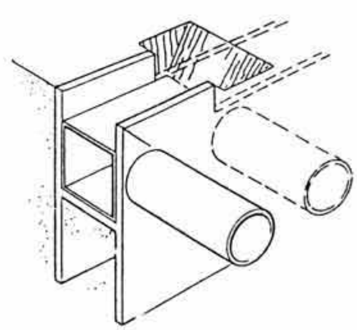
6 CIRCULAR DIAPHRAGM VAULTS
(Bradwell)



8 SQUARE VAULTS BETWEEN PARALLEL DIAPHRAGM WALLS
(Elstow, Fulbeck, Killingholme)



10 SHAFT VAULTS
(Bradwell, Fulbeck)



11 TUNNELS AND ACCESS TRENCH
(Bradwell)

Fig. 1. Vault designs selected for analysis.

of a site with deep aquifers, where distance to finished ground is the relevant factor, a deep vault will be more favorable solution. If shallow aquifers are present, a thin shallow vault may be more favorable. The larger this parameter, the better. One should note that the distance to the biosphere from the edge of the vault (as opposed to center of gravity) may also be important. However, it is not considered here, as all vaults are at a fixed distance from finished ground.

Depth-Normalized Specific Surface (DSS)

This parameter is a measure of the area of the intersection of the diffusion plume with the ground surface or nearest aquifer.

$DSS = A_G/V_v.L_p.$

A_G = Projected area of vaults on ground surface or aquifer

V_v = Volume of vaults

L_p = Distance to ground surface or nearest aquifer, whichever is smallest.

The depth-normalized specific surface is also an indication of the orientation of a vault. For instance, two cylindrical vaults of equal dimensions but orientated vertically or horizontally will have different depth-normalized specific surfaces. The smaller the value of this parameter, the better. This assumes, as does the following item, that diffusion is the dominant transport mode. This matter is dependent on local conditions and the results of the site investigations.

Depth-Modified Projected Area (DPA)

The greater the concentration gradient that drives diffusion, the smaller the resistance of the vault to loss by diffusion. This can be measured by the ratio $DPA = A_G/L_p$. The smaller the ratio, the better.

Ground Disturbance

This considers the extent to which the 'containment' capability of the original ground is reduced or increased by the evacuation during construction. Whether it reduces or increases depends on the quality of the original strata concerned (site specific) e.g. the presence of 'micro-aquifers' such as sand lenses, which could be removed by excavation. This can be represented by a series of parameters.

- Volume (V_e) of external excavation
- Max depth (D_e) of excavation
- Permeabilities of original (P_o) and backfilled ground (P_b)

For good original ground, ($P_o < P_b$), the best solution is the one that minimizes V_e, D_e and P_b. For poor original ground ($P_o > P_b$), the best solution is the one that maximizes V_e, D_e and P_b. In the absence of detailed site investigation results, it was not possible to rank the options at the various sites. A value for this parameter was therefore not included in the comparison table. However, it was felt useful to bear it in mind for use if site investigations and compaction trials are available.

Stress State Due to Ground Loading (SS)

The general shape and orientation of the vault will affect its general state of stress (compression or tension) due to ground loading, and hence its susceptibility to cracking and increased permeability. The 'ideal' shape is a sphere, being uniformly in compression. The worst is a long, narrow rectangle, having extensive zones of tension. SS can be expressed as the ratio of maximum dimensions (L) to minimum dimension (ℓ) in vertical and horizontal directions, and the designer should attempt to minimize its value:

$$SS = \left[\frac{(L_V \cdot L_H)}{(\ell_V \cdot \ell_H)}\right]$$

Weighted Thickness of Outer Migration Barrier (MBT)

The total thickness of all barriers 'guarding' the waste packages, which must be penetrated by water, measures the degree of resistance to water. This can be split into two components viz "membrane" and "non-membrane" migration barriers. The membrane being an option on all vaults except one, it is not considered in the comparison. Instead, the non-membrane barrier thickness is compared as it reflects the minimum engineered thickness. In this comparison, only the vault structure itself is considered, not the infill, waste package or waste matrix, as the latter are approximately the same on all vault designs. The weighted outer barrier thickness is given as:

$$MBT = \Sigma_i \left[\frac{(1-J_i)t_i}{P_i}\right]$$

i = 1: in situ concrete

i = 2: pre-cast concrete

i = 3: diaphragm wall concrete

t_i = thickness of barrier

P_i = permeability relative to in-situ concrete

J_i = fraction of outer surface taken up by joints

For the purpose of this comparison values are ascribed to parameters P and J by judgement; P_i is taken as unity for both in-situ and pre-cast concrete, and as 10 for diaphragm wall concrete reflecting differences in concreting conditions. J_1 is taken as 0%, J_2 as 6% and J_3 as 0.1% based on a notional frequency and width of joints. Expert opinion on the values of J can vary widely, but in our experience we found that all experts agree at least that $J_2 > J_3 > J_1$. The greater MBT, the better.

Resistance to Attack (RA)

In the long term the quality of the barriers will be affected by chemical and biological attack, the severity of which depends on the depth below ground surface and the specific area A_s. RA is expressed as:

$$RA = \frac{L_p}{A_s} = \frac{L_p V_v}{A_v}$$

L_p = distance to ground surface

V_v = volume of vault

A_v = area of vault

The larger RA, the better.

Concrete-to-Waste Ratio (CWR)

The pH of water within a repository is of crucial importance. A high pH is helpful in that it retards corrosion of steel (membranes, reinforcement). It also reduces the solubility of many nuclides, particularly actinides, and helps suppress microbial activity. Concrete is an excellent material as it establishes a high pH when in contact with water. It is reported to retain its buffering capacity for up to 400 times its own volume in groundwater flow. Therefore, the amount of cement and concrete present, per unit volume of packaged waste will provide a measure of the duration of the high pH value. The greater the ratio, the better.

Resistance to Intrusion

Together with migration of nuclides in groundwater, intrusion represents a potential route for exposure of man to the contents of the repository. The resistance to intrusion will depend largely on the following factors.

Depth of Cover

The deeper the vault, the less risk of intrusion. In the designs presented here, all vaults are at a nominal depth of 5m. They are thus in principle equal from this point of view. However, some designs offer the potential for being constructed at greater depths without incurring major difficulties. The tunnels can be taken as deep as the technology will permit, certainly deeper than the strata considered in this study. The shafts can also be taken deep, as in mines; they are amenable also to lowering the lid level without changing the base level, but this does leave unused structure above the vault for its whole plan area. Diaphragm walls can be constructed to greater depths, at the expense of increased propping and some uncertainty on the maintenance of good quality. Open cutting can also be increased in depth at the expense of larger volumes of excavation, left open for increasing lengths of time. Hence, a ranking of the options is possible, reflecting the ability to increase depth; the best being tunnels, followed by shafts, with other designs ranked last.

Visibility

The extent to which the ground cover attracts attention to the presence of vaults will affect the risk of intrusion. Although it is said that a visible sign of the presence of the vault may deter intrusion, it is thought that, on balance, the absence of a tumulus is an advantage. Hence, one can rank the options as being best without a tumulus, and worst with a tumulus.

Total Plan Area (TPA)

The greater the total plan area of the vaults, the greater the probability of intrusion from such activities as drilling or excavating.

RESULTS

Bradwell

Table I is a comparison of the concepts for Bradwell, carried out using the analysis described above. It shows that the shaft appears on balance to be the best option. This is because of the favorable vertical orientation, the low stress state, low ground-projected area, large average distance to biosphere and favorable surface to volume ratio. A number of factors mitigate against the tunnel option, but it has one marked advantage: the ability to exploit the full depth of clay.

Elstow

The differences between options were less marked at Elstow than at Bradwell. The eggbox vault appeared to be the least favorable option mainly because of its large specific and absolute areas. There seemed to be little to choose between the other two options.

Fulbeck

The analysis showed a clear preference for the shaft vault for the same reasons as given for Bradwell.

Killingholme

The analysis showed a slight preference for the tank vault at Killingholme because of a higher resistance to attack, better migration barrier (steel and concrete), and type of cover. There appears to be little to choose between the remaining options.

CONCLUSIONS

The cost and feasibility of shallow repositories can be estimated with some precision but the equivalent precision

TABLE I

Comparative Radiological Assessment of Vaults for Bradwell

	Open cut	Circular dia. wall	Tunnel & trench	Shaft
A. Resistance to migration in groundwater				
1. Flow project area (m^2)	123596	124955	246884 & 45405	* 36826
2. Specific vault area (m^2/m^3)	0.65	0.66	! 1.74 & 1.09	* 0.59
3. Distance to biosphere (m)	10	10	8.2 & 9.35	* 22.5
4. Depth normalized specific surface (m^2)	0.011	0.01	! 0.027 & 0.014	* 0.001
5. Depth modified projected area (m^2)	! 78	57	28 & 20	* 9
6. Ground disturbance (Rank)	?	?	? & ?	?
7. Stress state due to ground loading	1	1	4.5 & 1.5	1
8. Migr'n barrier weighted thickness (m)	1	0.4	0.8 & 0.1	>0.8
9. Resistance to attack	23.8	25.3	! 10.5 & 14.2	* 64
10. Concrete to waste ratio	1.07	1.54	* 2.46 & 2.93	1.48
B. Resistance to intrusion				
1. Depth of cover (m)	5	5	5 & 5	5
2. Ability to incr. depth (Rank)	! III	! III	* I & III	II
3. Visibility (Rank)	I	I	I & I	I
4. Plan area (m^2)	123596	124955	246844 & 45405	* 36926

* - clear best ! - clear worst

in long-term safety is only available from elaborate and expensive analysis. It is unsatisfactory either to ignore the long-term safety (because unquantified) or to take decisions on the basis of intuition untested by analysis. Therefore a method was devised to rank shallow vault design options with respect to their post-closure performance. This is based on mathematically expressing qualitative performance criteria. Fourteen parameters were used, and their evaluation allowed the ranking of vault design options at four clay sites with slow upward water movement. The set of parameters can be applied at a given site or could even be used to compare sites. It is believed that the same type of methodology can be used at sites with other geological and hydrogeological characteristics. Although the method is not perfect, and ideally it would benefit from some "calibration", it brings the long-term safety assessment into the decision-making process with regard to the screening of design concepts in a way that is both logical and practical.

REFERENCES

1. Nirex Near Surface Repository Project Preliminary Radiological Assessment, Summary. D P Hodgkinson, PC Robinson Nirex NSS/A100, November 1987.

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