THE SITING AND SYSTEM PERFORMANCE OF LOW LEVEL WASTE DISPOSAL FACILITIES

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INTRODUCTION

The Retention Quotient (RQ) methodology developed under sponsorship of the Electric Power Research Institute has been introduced as a systems analysis approach to quantify the isolation needed for nuclear wastes and to provide a basis for developing criteria applicable to the disposal of such waste.[1] The initial application of the RQ methodology was to high-level waste. This methodology has now been applied to low-level waste (LLW).

The results of the application reveal that tradition as shallow land burial facilities have sufficient containment for most environmental pathways, but certain postulated on-site reclaimer events can present potential problems. However, most of these problems can be mitigated by appropriate site selection, facility design and waste form criteria.

The systems-oriented performance objectives, specified in draft 10CFR61,[2] allow for the flexibility provided in the RQ methodology to perform tradeoff analyses with the site selection and facility design parameters.

DEVELOPMENT OF THE METHODOLOGY

In nuclear waste disposal, the impact on man is directly related to the hazard of the waste and inversely related to the containment provided by the disposal facility. Both factors must be considered in evaluating the safety of disposed waste.

In the RQ methodology, the hazard of the waste is given by the product of the nuclide inventory, Q, and its radiotoxicity, as measured by its dose conversion factor, DF. Combining this with the Dose Criteria, DC, for the impact, yields the Retention Quotient, RQ.

$$RQ = \sum_i RQ_i = \frac{Q_i \ DF_i}{DC} , \tag{1}$$

where the sum is over all isotopes, i, in the waste.

The magnitude of RQ specifies the degree of containment a waste burial site must achieve in order to satisfy the safety criteria, DC.

An additional factor that has been introduced into the methodology is the Performance Quotient, PQ, given by Eq. (2).

$$PQ_i = \frac{Q_i \ DF_i}{D_i} \tag{2}$$

The degree of containment actually provided by a particular disposal faiclity is measured by PQ. Use of PQ as the actual containment term yields the actual dose, D, as the impact; hence, the following relation is established:

$$\frac{DC}{D} = \frac{PQ}{RQ} = SF \tag{3}$$

This ratio, called the Safety Factor (SF) is an excellent overall factor that characterizes the safety of the disposed waste because it relates the potential hazard of the waste with the barriers provided by the disposal facility. This is equivalent to relating the potential dose to the dose criteria.

The magnitude of PW is determined by the barriers existing in the various pathways that the waste can take to reach the receptor.

Unlike high-level waste disposal, there are many pathways for disposed LLW. These pathways can be grouped into the off-site transport of the waste and on-site intrusion into the waste by a land reclaimer. The major pathways and the restricting barriers associated with them are listed in Table 1.

Equation 2 is not used to obtain the magnitude of PQ_i because D_i is not generally known. Comparison of Eq. (2) with standard pathway yields quantitative expressions for PQ_i and for the barriers in the pathway.[3,4] For example, one of the more significant pathways is the intruder-food pathway in which individuals unknowingly occupy the land and grow food for their own consumption. The annual dose received by an individual is given by:[2,4]

$$D_i = \frac{C_i f_d \ (DF)_i f_g \ U:}{\rho_s} \tag{4}$$

where

D_i = annual dose from nuclide i (mrem/yr)
C_i = concentration of nuclide i in the waste (Ci/m^3)
f_d = dilution fraction of waste with soil
f_g = fraction of food consumed by an individual that is grown on-site
ρ_s = soil density (kg/m^3)
U_i = total effective uptake factor for the food pathway (kg/yr)

The term U_i accounts for the consumption of the radionuclides, directly and indirectly and is a summation over the plant mixing factors, vegetation consumption rate by man and animals, and meat and milk consumption rates by man. It is calculated in the manner specified in Ref. 5.

Dividing D_i by DC and rearranging yields

$$\frac{DC}{D_i} = \frac{DC}{Q_i\ (DF)_i}\ \frac{V\rho_s}{f_d f_g U_i}\ , \tag{5}$$

where C_i has been replaced by Q_i/V, with V being the waste volume.

Comparison of Eqs. (5) and (3) yields for PQ:

$$PQ_i = \frac{V\rho_s}{U_i f_g f_d} \tag{6}$$

Expressions of PQ_i for other pathways are obtained in a similar fashion.[3]

In Eq. (6) the waste dilution barrier is given by $V\rho_s$; i.e., for a fixed Q_i, the larger V is, the more dilute the waste. The magnitude of the soil mixing barrier is given by $(1/f_d)$. It is assumed that f_d decreases with increasing burial depth. The fraction of waste that is brought to the surface and is mixed with garden soil decreases as the waste is buried deeper. The term f_d is given by

$$f_d = f_m\ \frac{(x_m - x_c)}{x_g(f_h^{-1} - 1)} \tag{7}$$

where

f_m = mixing fraction of waste in the trench
x_m = maximum depth of disturbance in constructing dwelling (m)
f_h = fractional area occupied by dwelling
x_c = waste cover thickness (m)

Typical values of these parameters are:
x_m = 3, x_g = a, f_m = 0.5, and f_h = 0.05.

The environmental pathway barrier is $U_i f_g$. The resulting RQ and PQ for ^{90}Sr for the intruder-food pathway in a reference operations waste inventory and facility[2] are shown in Fig. 1. Group 4 wastes from Ref. 2 are not included in this example. The DF factors are from Ref. 6.

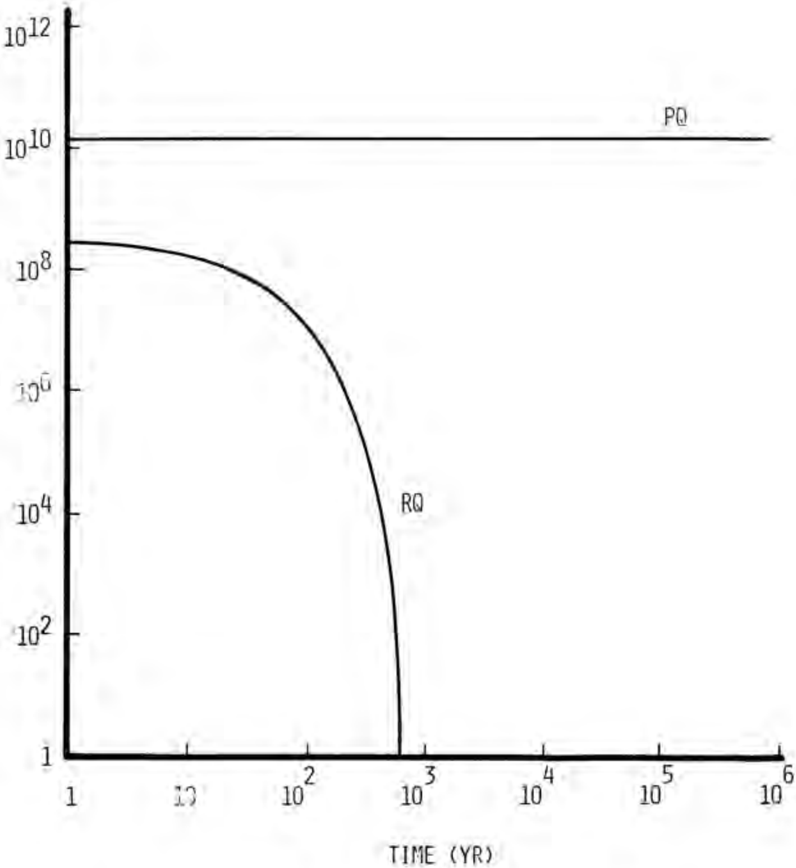

Fig. 1. RQ AND PQ FOR 90 Sr IN THE INTRUDER-FOOD PATHWAY

As shown in the figure, RQ decreases rapidly with time owing to the relatively short half-life of ^{90}Sr, but RQ is constant over time in this example. The PQ can also be time-dependent. For example, if surface erosion occurred then PQ would decrease with time.

The PQ for a mixture of waste is obtained from the relation:[3]

$$\frac{1}{PQ} = \sum_i \frac{RQ_i}{RQ} \frac{1}{PQ_i} \tag{8}$$

This means that the inverse of the resulting PQ is obtained as a sum of the inverses of the PQ_i, each weighted by RQ_i/RQ, which is the isotope's fractional contribution to RQ.

The pathway RQ and PQ are combined in the same manner as specified by Eqs. (1) and (8) to obtain a facility RQ and PQ, except that for this application the indices apply to all pathways being considered.

APPLICATION AND DISCUSSION

Values of the RQ, PQ and for the facility overall safety factor SF are shown in Figure 2. The waste inventory and reference site parameters are again from Ref. 2. As shown in the figure, the PQ exceeds RQ for all times greater than ten years after closure; thus the SF exceeds unity for these times. In this calculation the intruder food and well pathways are most significant, although the inhalation pathway becomes significant at very long times.

The main advantages of the RQ-PQ methodology and computer model are its simplicity of operation and presentation while at the same time allowing for a comprehensive set of nuclides and pathways to be treated. Critical isotopes and pathways are readily identified. Low-level waste disposal site performance and facility conceptual designs can be quickly investigated with relatively few parameters needed to define the problem. For example, key site parameters include:

- depth to the aquifer
- aquifer distance to accessible location
- aquifer velocity
- facility size
- soil retardation characteristics
- precipitation
- depth for emplacement of waste

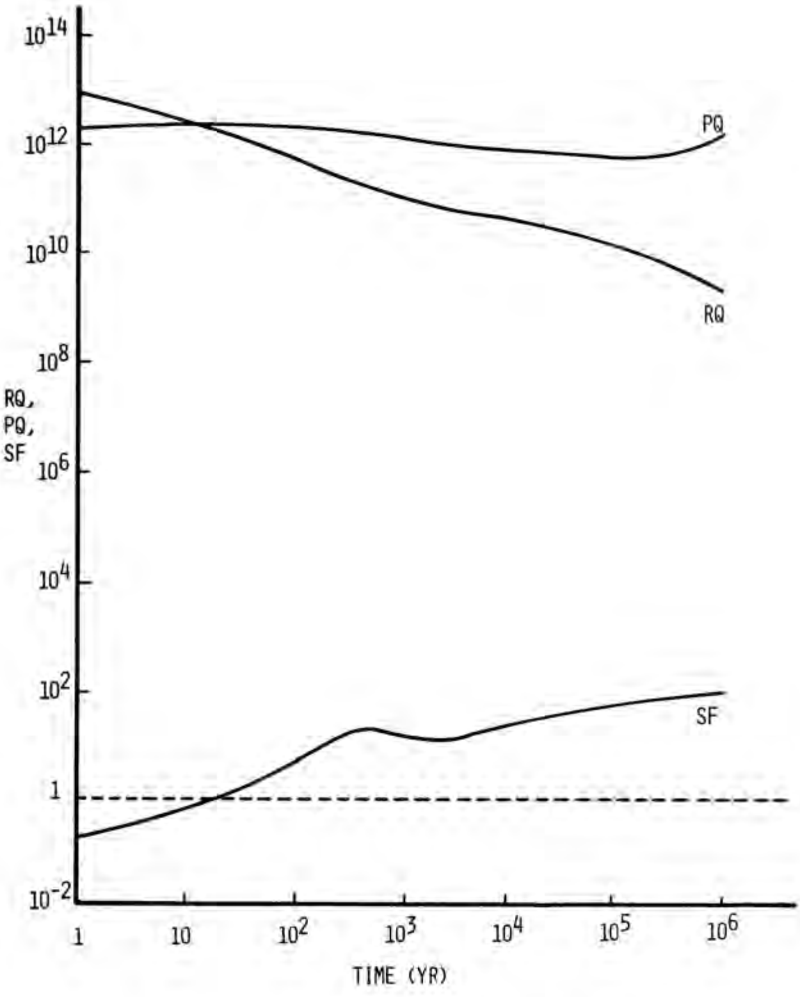

Fig. 2. RQ, PQ, SF FOR REFERENCE LLW IN A FACILITY

- cover thickness
- cover impermeability

The user has the option of specifying his own set of waste leach constants or, if desired, they may be calculated by using the RQ-PQ code using infiltration rates from precipitation as the mass transfer exchange medium.

For most shallow land burial facilities the inadvertent intrusion scenarios dominate the evaluation of site performance. Thus, it is desirable to locate a new LLW disposal site away from areas with a high potential for future population growth. Area exclusion criteria given in 10CFR61 are consistent with this objective. Deeper waste disposal also helps mitigate most surface intrusion pathways. For example, Fig. 3 contains safety factors

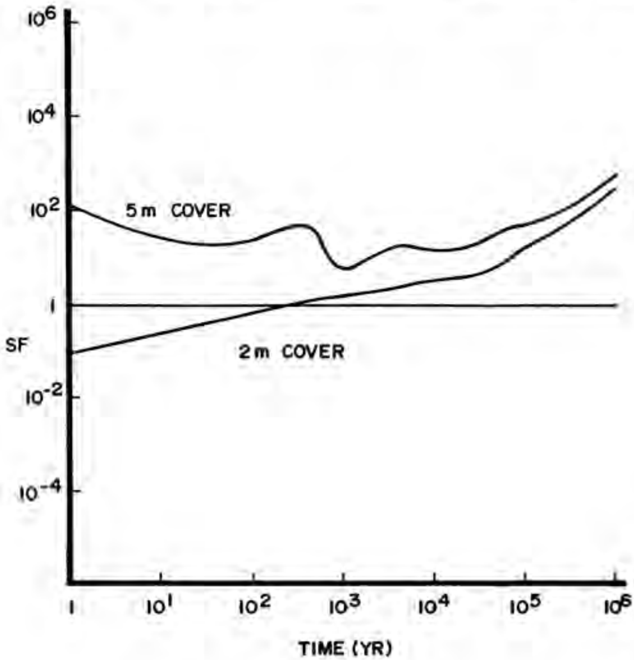

Fig. 3. SAFETY FACTORS FOR REFERENCE FACILITY AND WASTE INVENTORY AS A FUNCTION OF COVER THICKNESS. THE REFERENCE WASTE INCLUDES GROUP 4.

for a facility in which the waste has either a two-meter cover or a five-meter cover. The five-meter cover provides additional dilution of the waste. The annual probability of an intrusion event occurring is also reduced with the slightly deeper burial. The proposed regulations in 10CFR61 give a credit of 500 years before an intrusion event is postulated to occur if the waste is well-packaged and buried with at lease five meters cover.

Another desirable site feature that became evident in the development and application of the RQ-PQ is the need for simple site hydrology and geology. Many sites with a wide range of characteristics are suitable for the disposal of LLW. However, a major factor in licensing any site is the degree of confidence in the site performance analysis. Even though a site may exhibit some very desirable features such as high retardation coefficients and low permeabilities, if the hydrogeology of the site is complex then confidence in the ability of any model to predict future site performance is reduced. For example, the complexity could lead to the future development of cracks and fractures in an important geological formation which could allow for a hydraulic short circuit and significant degradation of site performance.

Finally, the safety of disposed LLW is a function of both RQ and PQ. If, for a particular site, the PQ does not exceed RQ, then reducing RQ should also be considered as well as increasing PQ. The waste sources for a particular site should be identified. If only one or two isotopes are the main reason that SF is less than unity, then the concentrations or inventories of those isotopes may be restricted. It may be that one or two waste generators are responsible for most of the inventory and for those isotopes and that extra precaution can be taken just for their waste so that the other waste generators are not restricted unduly.

SUMMARY

The RQ-PQ methodology is a simple, straightforward systems approach to evaluating the safety of a LLW disposal facility. The critical features of a particular site can be characterized by relatively few parameters which consititute the barriers to waste migration described by the performance quotient. In the methodology the site safety factor exceeds unity when the site satisfies the performance criteria; i.e., when the performance quotient exceeds the potential hazard of the waste to be disposed, quantified by the retention quotient.

TABLE I

PATHWAYS AND BARRIERS USED IN SYSTEMS ANALYSIS OF DISPOSED LOW LEVEL WASTE

	Barrier			
Pathway	Waste Form	Migration Barrier	Env. Dilution	Exposure Time
Groundwater	Leach Rate	Geologic Retention	River Dilution	--
Surface Erosion	Erosion Rate	Soil Mixing	River Dilution	--
Inhalation Reclaimer	Waste Dilution	--	Atmos. Dilution	Exposure Time
Well Water	Leach Rate	Geologic Retention	Aquifer Dilution	
Direct Exposure	Waste Dilution	Shielding	--	Exposure Time
Food Reclaimer	Waste Dilution	Soil Mixing	Uptake Limits	--
Radioactive Gases	Emanation Fraction	Soil Rentention	Atmos. Dilution	Exposure Time

REFERENCES

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6. International Commission on Radiation Protection, Publication ICRP-30 (1980).