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Abstract

A preliminary reliability analysis of container lifetime was performed on the basis of the Basalt Waste Isolation Project (BWIP) container corrosion models. The preliminary analysis was conducted using Monte Carlo simulations of the input parameters. Two distributions were assumed for the input variables, viz., normal and uniform distribution. Cumulative probabilities to achieve specific container lifetimes were calculated from the container lifetime data. The results indicated that the reference low-carbon steel waste containers may not fail prior to 1000-year containment time regardless of the choice of the expected scenario and the selection of the distribution type for the input parameters. Therefore, it is concluded that the low-carbon steel containers are very likely to meet the Nuclear Regulatory Commission (NRC) requirements.

Key Words: Container, Lifetime, Low-Carbon Steel, Monte Carlo Simulation, Reliability

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PRELIMINARY RELIABILITY ANALYSIS OF CONTAINER LIFETIME

R. P. Anantatmula

1.0 INTRODUCTION

The Engineered Barriers Department within the Basalt Waste Isolation Project (BWIP) has the ultimate responsibility for the development and design of waste packages suitable for containment of high-level nuclear waste in a repository constructed in basalt. These waste packages, according to current proposed Federal regulations [1], must successfully provide containment of the waste and isolate the waste from the groundwater environment for a minimum of 300 to 1000 yr after emplacement. Therefore, successful long-term performance in the expected hydrothermal environment of the repository is an important criterion in the selection of a material for container fabrication.

The reference container material used in the BWIP Reference Waste Package Conceptual Design is low-carbon steel. The thickness of the new reference low-carbon steel container is 8.3 cm (3.27 in). The present report provides a preliminary reliability analysis of container lifetime based on the reference container thickness and the BWIP container corrosion models [2]. The container corrosion models are preliminary in nature, and the models will be upgraded as more experimental data under simulated repository conditions are obtained. Probabilistic analysis will then be performed on the improved corrosion models.

2.0 MODELING APPROACH

The basic underlying assumptions of the preliminary BWIP container corrosion models were described in detail in Reference 2. Although a pitting model was derived in Reference 2, pitting was not included in the present calculations because of the limited data (obtained under severe test conditions) on which the pitting equation was based. For the current analysis, the container lifetime is defined as the time at which the corrosion allowance is completely consumed.

Two cases were considered for the present analysis, viz., (1) Reference or base case in which the repository is assumed to be saturated immediately upon closure, which was assumed to occur at 100 yr after emplacement, and (2) Bounding or performance limits case in which the repository is assumed to experience the worst-case situation of resaturation at 300 yr after emplacement. According to the Reference 2 models, these two cases constitute the lower and upper bounds for corrosion respectively. This is because the exposure of low-carbon steel container to groundwater saturated packing at the higher temperature (200°C - 250°C) leads to the formation of a protective iron-rich clay [3], which reduces the corrosion rate of the steel. However, at lower temperatures (e.g., 100°C) the corrosion rate is a factor of ~7 higher which is attributed to the slow reaction kinetics for the formation of the iron-rich clay [4]. The models assume the container temperature to drop to 125°C at 300 years and the corrosion rate at ≤ 125°C is assumed to be the same as that at 100°C. Other scenarios are expected to fall between these two limiting cases.

The present probabilistic analysis was carried out utilizing Monte Carlo simulations of the input parameters. The distributions assumed for the input variables are normal and uniform distributions. The computer code for the Monte Carlo simulation requires the mean and standard deviation for the normal distribution and the upper and lower end points for the uniform distribution. The values supplied as input for the various parameters are consistent with the uncertainty values assumed in the recently prepared sensitivity analysis document [5]. A thousand sets of samples were selected from the input parameter distributions and the container lifetimes were calculated for each set of sample parameters. From the container lifetime data, cumulative failure probabilities were calculated and plotted against container lifetimes. The container reliability is the complement of the cumulative failure probability i.e., Reliability = 1 - (cumulative failure probability).

3.0 RESULTS

The results of the Monte Carlo simulation of the container lifetimes are listed in Tables 1 to 4 and illustrated in Figures 1 to 4. According to the data, the cumulative probability of container failure prior to 1000 yr is less than 0.001 regardless of the choice of the scenario (base case or the worst case) or the distribution type for the input parameters. In other words, the results indicate that less than 1 in 1000 containers will fail prior to 1000 yr. (i.e., the reliability is 0.999). However, there are slight differences in the container lifetime versus probability curves for the individual distributions. For the base case (immediate resaturation at closure), the cumulative probability of failure is less than 0.001 prior to 4905 and 4729 yr; and 100% failures are expected prior to 8848 and 8810 yr, respectively, for the normal and uniform distributions (see Tables 1 and 3). For the worst case (300 yr resaturation time), less than 1 in 1000 containers is expected to fail prior to 1411 and 1470 yr (i.e., the reliability is 0.999) and 100% failures are expected prior to 2622 and 2533 yr for the normal and uniform distributions, respectively (see Tables 2 and 4).

4.0 CONCLUSIONS

The present results indicate that the reference low-carbon steel waste containers may not fail prior to 1000 yr containment time regardless of the choice of the expected scenario and the selection of the distribution type (normal or uniform) for the input parameters. Thus, a preliminary conclusion is that the low-carbon steel containers are in compliance with the Department of Energy Headquarters suggested guidance of 300 yr (performance limits case) and 1000 yr (reference case) containment times, and also the Nuclear Regulatory Commission regulations [1].

At the present time, it is not certain what type of distribution best represents the input parameters. With the expansion of the data base in the future, the actual distribution of the model parameters may become apparent. Therefore, it is suggested that the average container lifetime for the reference 8.3 cm (3.27 in) thick low-carbon steel container is 2000 ± 600 yr,

assuming the worst case scenario (see Table 2). For the base case, a mean lifetime of 6500 ± 2000 yr is recommended (see Table 1).

It should be pointed out that the present probabilistic analysis was based on corrosion models that are preliminary in nature, and assumed uncertainties of input parameters. As more experimental corrosion data at long times become available, some of the assumptions made in the corrosion models can be eliminated resulting in a refinement of the models. This, in turn, will increase the confidence in future probabilistic analyses.

5.0 ACKNOWLEDGEMENTS

Thanks are due to Mr. D. W. Langford for the assistance in performing the Monte Carlo simulations.

6.0 REFERENCES

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Table 1

Cumulative Probability of Container
Lifetime for Normal Distribution
(Resaturation Time = 100 yr)

Cumulative Probability	Container Lifetime (Years)
0.0010	4905
0.0500	5343
0.1000	5507
0.1500	5624
0.2000	5713
0.2500	5812
0.3000	5876
0.3500	5952
0.4000	6036
0.4500	6101
0.5000	6171
0.5500	6257
0.6000	6338
0.6500	6412
0.7000	6509
0.7500	6598
0.8000	6725
0.8500	6862
0.9000	7052
0.9500	7341
1.0000	8848

Table 2

Cumulative Probability of Container
Lifetime for Normal Distribution
(Resaturation Time = 300 yr)

Cumulative Probability	Container Lifetime (Years)
0.0010	1411
0.0500	1634
0.1000	1677
0.1500	1704
0.2000	1731
0.2500	1754
0.3000	1776
0.3500	1795
0.4000	1813
0.4500	1834
0.5000	1853
0.5500	1870
0.6000	1893
0.6500	1911
0.7000	1938
0.7500	1965
0.8000	1991
0.8500	2035
0.9000	2080
0.9500	2159
1.0000	2622

Table 3

Cumulative Probability of Container Lifetime for Uniform Distribution (Resaturation Time = 100 yr)

Cumulative Probability	Container Lifetime (Years)
0.0010	4729
0.0500	4914
0.1000	5034
0.1500	5144
0.2000	5266
0.2500	5403
0.3000	5552
0.3500	5691
0.4000	5850
0.4500	6004
0.5000	6166
0.5500	6366
0.6000	6532
0.6500	6752
0.7000	6976
0.7500	7194
0.8000	7490
0.8500	7740
0.9000	8061
0.9500	8361
1.0000	8810

Table 4

Cumulative Probability of Container
Lifetime for Uniform Distribution
(Resaturation Time = 300 yr)

Cumulative Probability	Container Lifetime (Years)
0.0010	1470
0.0500	1522
0.1000	1548
0.1500	1581
0.2000	1615
0.2500	1648
0.3000	1686
0.3500	1725
0.4000	1758
0.4500	1806
0.5000	1852
0.5500	1897
0.6000	1955
0.6500	2004
0.7000	2070
0.7500	2119
0.8000	2190
0.8500	2266
0.9000	2345
0.9500	2419
1.0000	2533

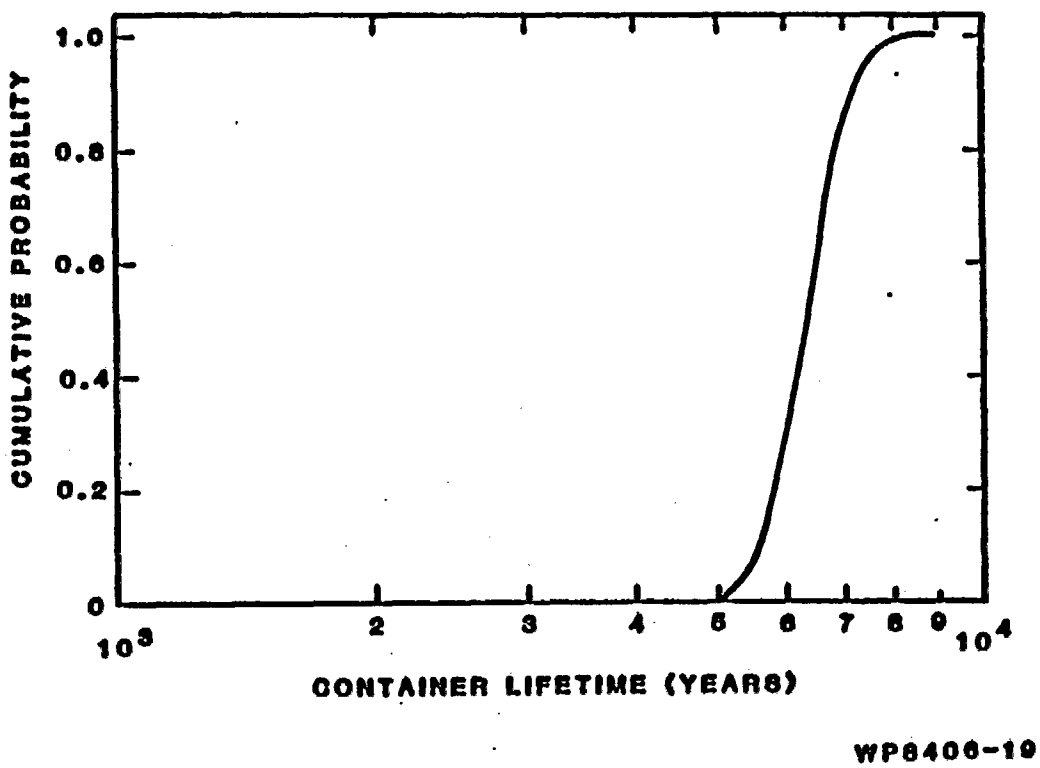

FIGURE 1. Cumulative Probability vs Container Lifetime Curve for Normal Distribution (Resaturation Time = 100 yrs)

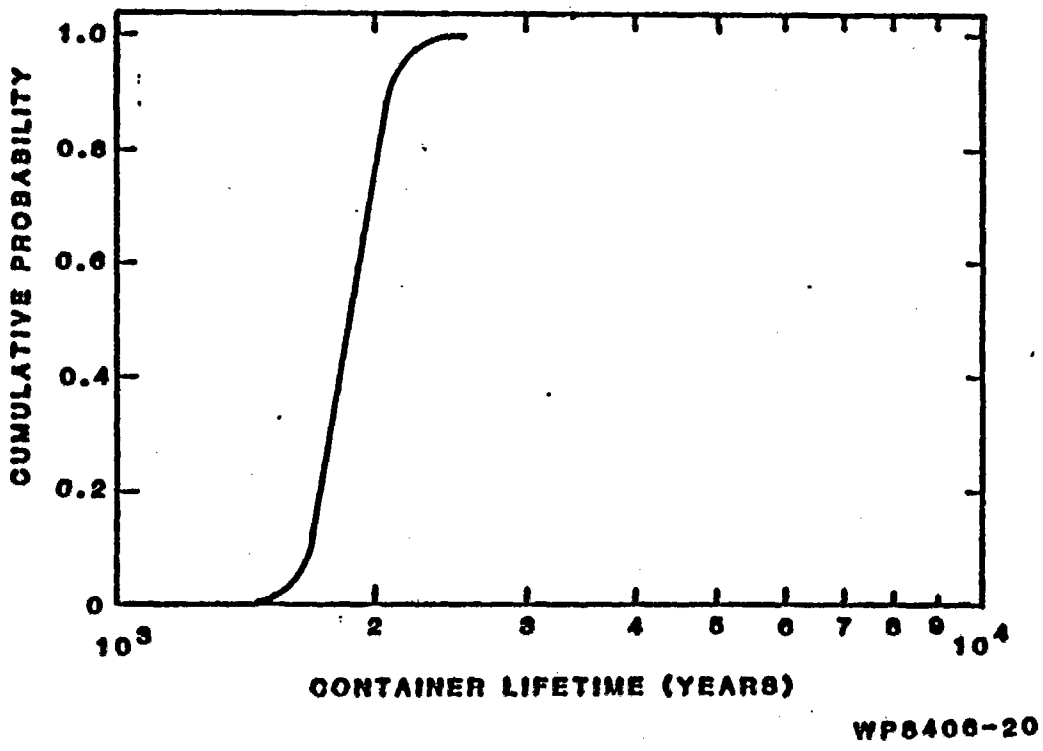

FIGURE 2. Cumulative Probability vs Container Lifetime Curve for Normal Distribution (Resaturation Time = 300 yrs)

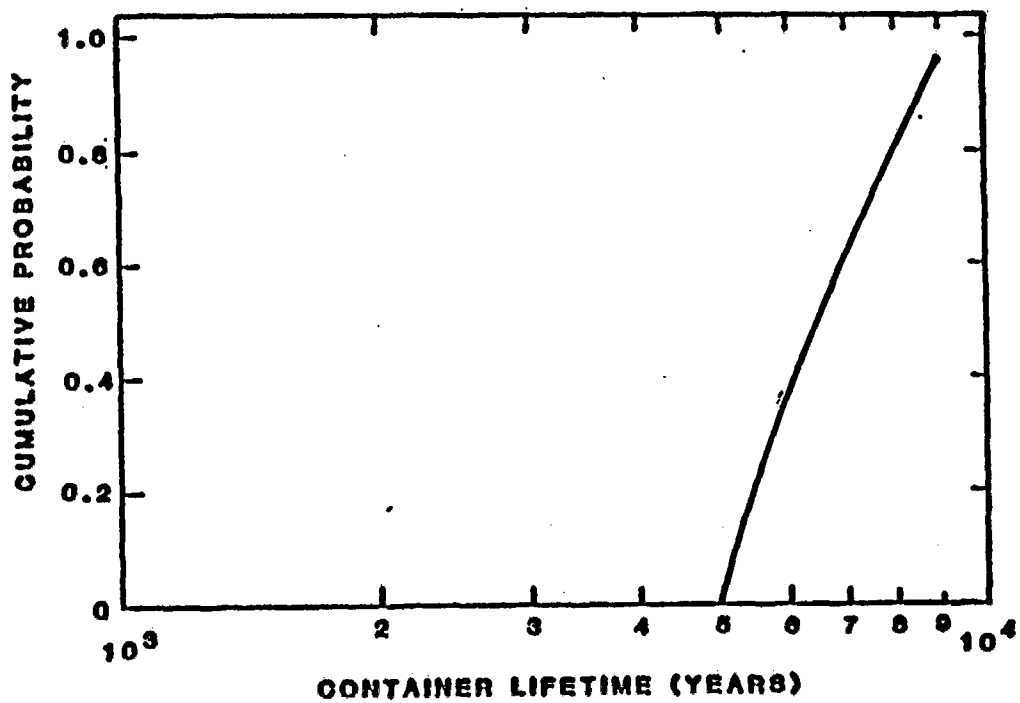

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FIGURE 3. Cumulative Probability vs Container Lifetime Curve for Uniform Distribution (Resaturation Time = 100 Years)

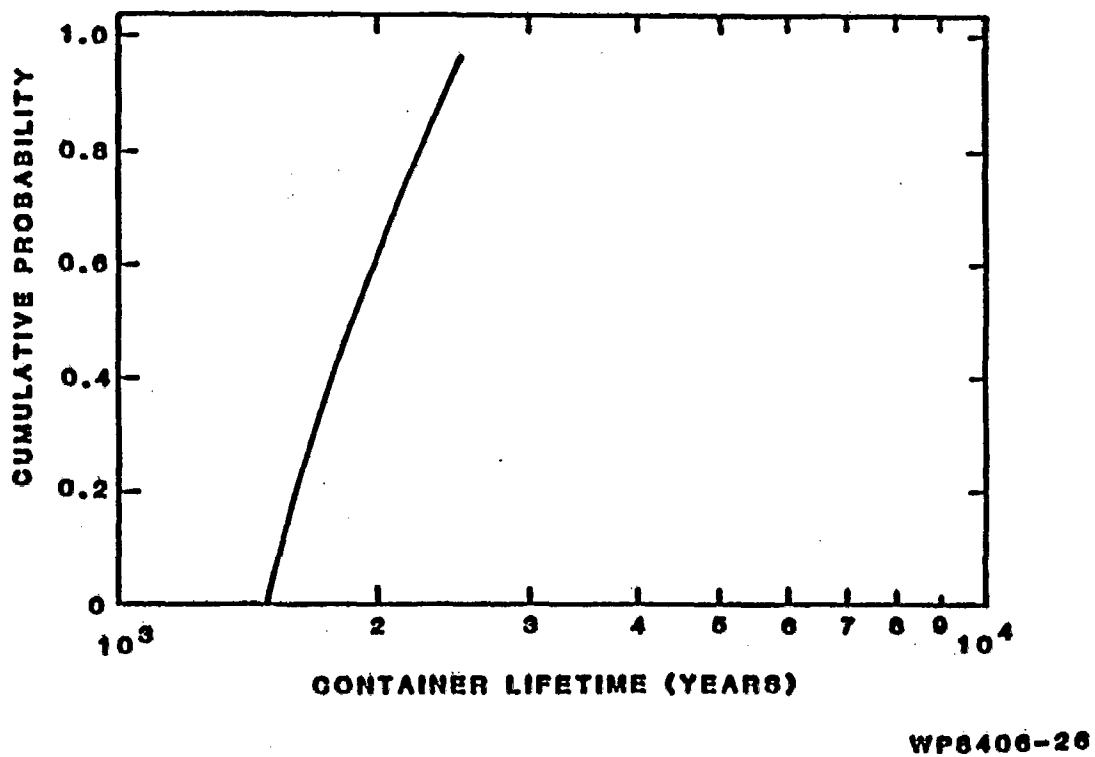

FIGURE 4. Cumulative Probability vs Container Lifetime Curve for Uniform Distribution (Resaturation Time = 300 Years)