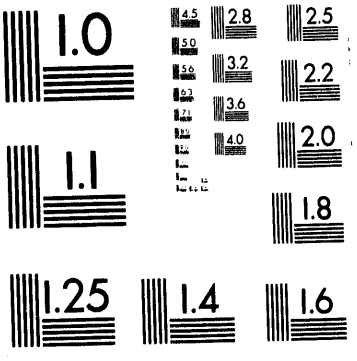
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4.5
5.0
5.6
6.3
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8.0
9.0

1 of 1

TABLE II

Drilling Analysis Parameters

Configuration	Repository Area (km^2)	P_{hit} (spent-fuel packages only)	N_{drill}[a]
TSPA-91			
141 kW/Ha, vertical	5.61	.0075	17
TSPA-2			
141 kW/Ha, vertical	3.32	.0171	10
141 kW/Ha, horiz.	3.32	.0324	10
282 kW/Ha, vertical	1.94	.0292	6
282 kW/Ha, horiz.	1.66	.0648	5

[a]Drilling density based on three borehole/km^2/10 000 yr (Ref. 3).

CONCLUSIONS

These analyses show that the choice of repository and waste package configuration can have a large impact on surface releases of radionuclides. The assumed benefits of an alternative waste package design must be weighed against the possible impacts on drilling scenarios. The human intrusion analyses are only one of many aspects being considered. Other factors, such as dose effects, susceptibility to other disruptive events, and operational considerations will all be evaluated. Because the design and the configuration of the potential Yucca Mountain nuclear waste repository are still being evaluated, performance assessment analyses such as this will provide valuable insight and guidance.

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2. "Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada," DOE/RW-0199, U.S. Department of Energy (1988).

3. Environmental Protection Agency (EPA), "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," 40CFR191, *Code of Federal Regulations* (1985).

4. Drilling Rates for Oil and Gas near the Waste Isolation Pilot Plant, *Matthew Silva (EEG)*

The drilling rates estimated by subjective elicitation[1] are four orders of magnitude less than the actual drilling rates for oil and gas near the Waste Isolation Pilot Plant (WIPP), a repository intended for the disposal of defense transuranic (TRU) waste. The 1985 U.S. Environmental Protection Agency EPA standards for the disposal of TRU waste specifically cautioned against building a repository in an area with resource potential "unless the favorable characteristics of such places compensate for their greater likelihood of being disturbed in the future."[2] The 1992 WIPP Land Withdrawal Act requires the U.S. Department of Energy to submit analyses to the EPA that demonstrate that the repository's release of radionuclides to the biosphere over the next 10 000 yr will be less than allowed by the EPA standards. These analyses rely on performance assessment calculations. The performance assessment calculations published to date have identified future drilling for oil and gas reserves as an event that can disrupt the repository and release radionuclides in excess of the standards.[3] The calculations are highly sensitive to the assumed drilling rates.[3]

Figures 1a and 1b (see next page) show the low drilling rates inferred from two "expert" elicitation exercises.[1] As shown, the EPA standards (40CFR191) specify a maximum drilling rate of 30 boreholes/km^2·10 000 yr for geologic repositories in proximity to sedimentary rock formations. For the last 9000 yr of the regulatory period, the raw drilling intensity inferred from the first elicitation exercise is only 0.4 boreholes/km^2·10 000 yr, and the marker moderated intensity inferred from the second elicitation exercise is only 0.2 boreholes/km^2·10 000 yr. This is three orders of magnitude less than the specified EPA maximum and at least four orders of magnitude less than the current drilling rate in the immediate vicinity of the WIPP.

Figure 2a (see next page) shows that by 1977 there were only 13 oil and gas wells drilled within 2 miles of the current WIPP site boundary. As noted by Keesey,[4] extensive deep drilling had not been undertaken in the New Mexico portion of the Delaware Basin, and only 10 to 15% of the available acreage had been tested. Keesey also stated that the Delaware Basin still had major oil and gas potential. Figure 2b (see next page) shows that there are now 80 additional oil and gas wells and 4 brine injection wells in this same vicinity. Most of these wells have been drilled in the last 3 yr on 40-acre spacing primarily for the exploration and production of crude oil. Even if drilling of those 80 wells had been distributed over the last 15 yr, the actual drilling rate still exceeds 400 boreholes/km^2·10 000 yr or a full order of magnitude greater than the EPA maximum value. In addition there are 68 notices of staking or applications for permit to drill. The applications are either pending or have been denied. This is also a potash resource area, and many applications for permission to drill for oil and gas have been denied by the Bureau of Land Management. If not for the potash reserves, the drilling rate would be even higher.

In conclusion, the low drilling rates inferred from the elicitation exercises should be viewed with caution. The performance assessment calculations need to justify a drilling rate, and that rate should account for actual experience and resource potential in the Delaware Basin.

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2. "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," U.S. Environmental Protection Agency, *Federal Register*, 50, *182*, 38066-38089 (Sep. 19, 1985).

3. "Preliminary Performance Assessment for the Waste Isolation Pilot Plant, December 1992, Third Comparison with 40 CFR 191," Subpart B, SAND92-0700, WIPP Performance Assessment Department, Sandia National Labs. (1992).

4. J. J. KEESEY, "Hydrocarbon Evaluation Proposed Southeastern New Mexico Radioactive Material Storage Site, Eddy County, New Mexico," SAND77-7033, Vol. I, Sandia National Labs. (1976).

5. Probability of Intrusion by Exploratory Drilling at the WIPP Site, *Martin S. Tierney (SNL)*

Inadvertent intrusion by exploratory drilling is a credible disruptive event that could lead to a release of radioactivity to the accessible environment from the Waste Isolation Pilot Plant (WIPP) site in southeastern New Mexico.[1] Since all credible disruptive events and processes must be considered in

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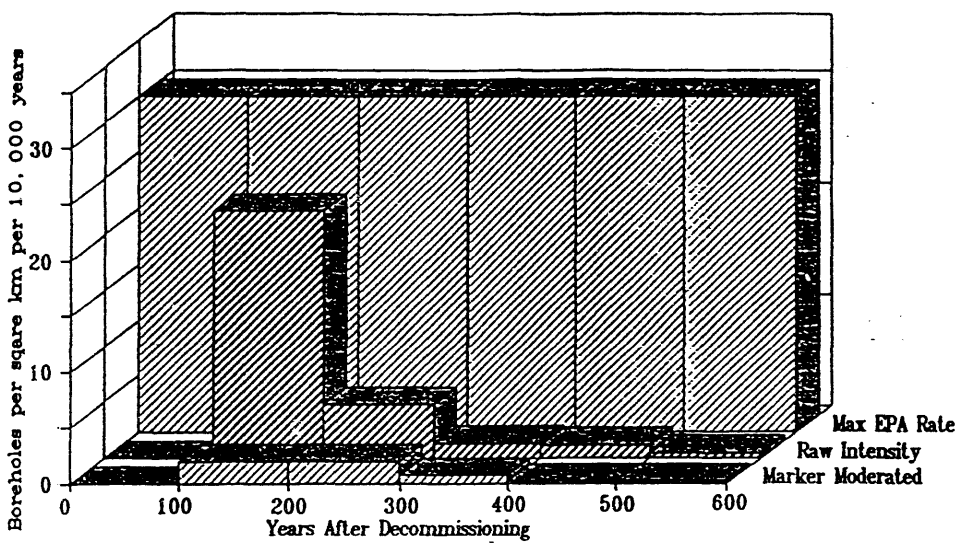
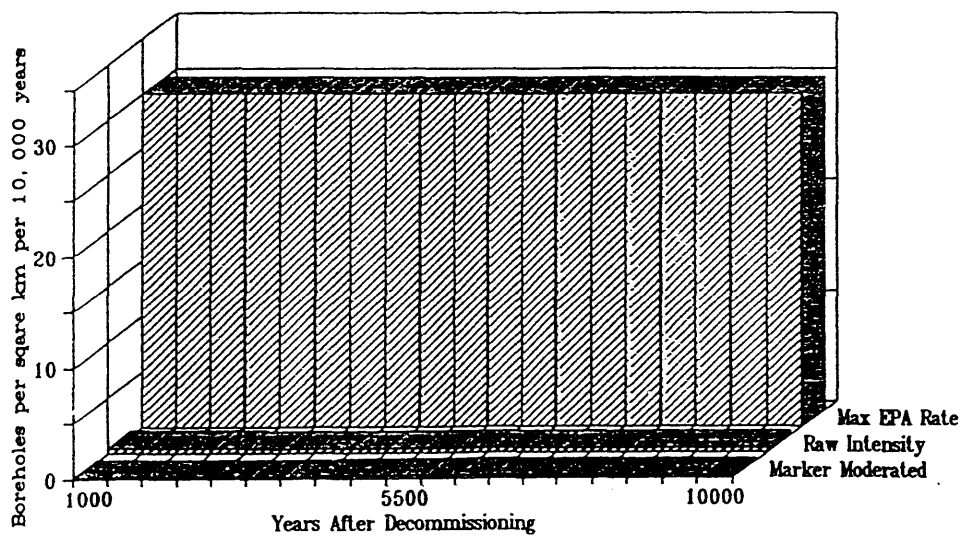
DISCLAIMER



(a)



(b)

Fig. 1. Drilling rates. [Mean drilling intensity (estimate by S. C. Hora, 1992).] (Paper 4)

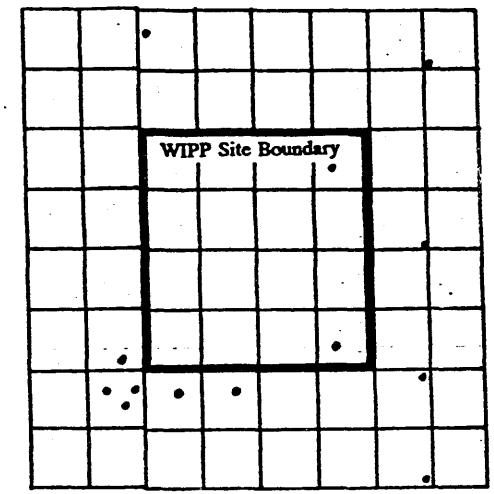
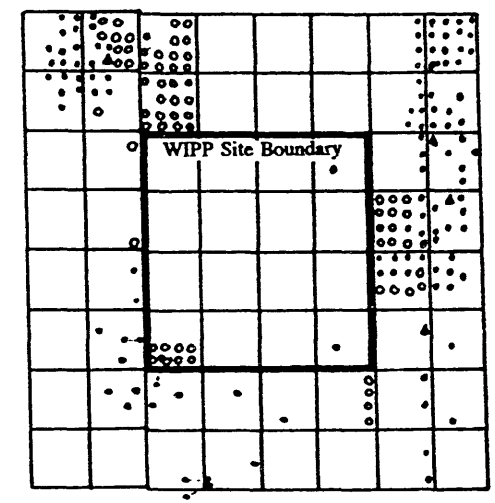


Fig. 2a. Oil and gas wells in 1977. (Paper 4)



- Oil and gas wells
- ▲ Brine injection wells
- o Applications for permit to drill and staking notices

Fig. 2b. Oil, gas, and disposal wells in 1993. (Paper 4)

determining compliance with U.S. Environmental Protection Agency (EPA) standards for disposal of high-level and transuranic wastes,[2] preliminary assessments of the performance of the WIPP system have necessarily examined the consequences and probabilities of scenarios that involve intrusion by exploratory drilling during a 10 000-yr period following site closure. Helton[3] and Tierney[4] have proposed probability models for exploratory drilling scenarios that are based on the assumption that the random variable $N(t)$, the number of exploratory boreholes that accidentally penetrate the repository by time $t > 0$ following site closure at time = 0, is a Poisson process,[5] i.e., a continuous-time random process whose state probabilities,

$$P_n(t) = \text{probability that } [N(t) = n] \ , \quad n = 0,1,2,3,\ldots ,$$

are solutions of the infinite system of equations

$$\frac{dP_0}{dt} = -\lambda(t)P_0 \ , \quad P_0(0) = 1$$

and

$$\frac{dP_n}{dt} = -\lambda(t)(P_n - P_{n-1}) \ , \quad P_n(0) = 0 \ , \quad n \geq 1 \ ,$$

where the "drilling intensity function" $\lambda(t)$ can be any nonnegative function defined on the interval $[0,\infty)$. The WIPP investigators have used both constant and time-dependent $\lambda(t)$ in the foregoing system of equations to calculate probabilities of intrusion by exploratory drilling[6]; in either case, $\lambda(t)$ has been treated as an imprecisely known parameter that is bounded above by λ_{max}, the maximum drilling intensity suggested in the guidance for implementing EPA standards in 40CFR191 (Ref. 2). In the constant-λ case, the parameter is sampled from a uniform distribution on the interval $(0,\lambda_{max})$; in the case of a time-dependent intensity function, the parameter is sampled from a set of equally likely realizations taken from a family of functions constructed from information provided by a panel of experts.[7,8]

All forms of Poisson processes share a feature—homogeneity in time—that may reduce their credibility as bases for probability models of the occurrence of events in the far future: In the models used for WIPP investigations, the drilling intensity function chosen at the start of a calculation must apply in every interval of time between successive pairs of future drilling events; i.e., the process is renewed with the same intensity function after each drilling event, no matter when that event occurs. The purpose of the work presented in this paper is to investigate the simplest generalization of a Poisson process that lacks this counterintuitive feature, i.e., the simplest probability model that can incorporate effects of random temporal variability of problem parameters. Motivation for this work stems from the belief that making fewer or less stringent assumptions enhances the credibility of models of hypothetical events.

The particular model studied in this work is a discrete-state, continuous-time birth process whose state probabilities are solutions of

$$\frac{dP_0}{dt} = -\lambda_0 P_0 \ , \quad P_0 = 1$$

and

$$\frac{dP_n}{dt} = -\lambda_n P_n + \lambda_{n-1} P_{n-1} \ , \quad P_n(0) = 0 \ , \quad n \geq 1 \ ,$$

where $(\lambda_n, n = 0,1,2,3,\ldots)$ is a sequence of positive, bounded numbers (constant drilling intensities) with $\lambda_j \neq \lambda_k$ for $j \neq k$. The method used in this work is a comparison of statistical properties of state probabilities generated by the former (Poisson) system of equations with statistical properties of solutions of the latter (non-Poisson) system of equations. The statistical properties of the solutions of each system are inferred by first numerically creating a large number of realizations (samples) of solutions of each system and then forming averages, variances, and empirical cumulative distribution functions from the sample data in the usual way.

To facilitate comparison of the latter (non-Poisson) system with solutions of constant-λ Poisson models used in the WIPP performance assessments, the elements of the sequence λ_n are treated as independent random variables to be sampled from a uniform distribution on the interval $(0,\lambda_{max})$; this way of choosing the sequences λ_n ensures that the associated sequences of state probabilities, $[P_n(t)]$, will be probability distributions in the sense that $P_n(t) \geq 0$, $n = 0,1,2,\ldots$, and

$$\sum_{n=0}^{\infty} P_n(t) = 1 \ .$$

Some anticipated results of the comparison of solutions of Poisson and non-Poisson systems are that (a) there is no significant difference between expected values of the sequences of state probabilities associated with each model, and (b) the difference in variances of the state probabilities associated with each model decreases with increasing order of terms; the variance of state probabilities associated with the Poisson model on average dominates the variance of the non-Poisson model. A practical implication of these results is that, in spite of their counterintuitive nature, constant-λ Poisson processes are conservative models of the probability of human intrusion by exploratory drilling in the sense that they lead to overestimates of the probability of the number of drilling events during the 10 000-yr period of performance.

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