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A MODEL TO PROJECT DOSE-TO-MAN FROM BURIED SOLID WASTE

by

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DISCLAIMER

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ABSTRACT

To plan for the postoperational surveillance and control of the Savannah River Plant solid waste burial site, a model is being developed to simulate movement of radionuclides from buried solid waste through the environment to man. Results from the study of the model will be used to validate current operating limits for burial and to establish criteria for future surveillance and control. A preliminary model has been formulated to estimate the rate and extent of ^{90}Sr movement through a set of aquatic (ground water, creeks, and river) and terrestrial (vegetation, animals, and dust) pathways. Estimates based on pessimistic assumptions show that drinking water from the shallow ground water table in the burial region is the critical pathway for dose-to-man. Current and planned experimental programs to refine model parameters will be presented.

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INTRODUCTION

One centrally located solid waste storage site (Fig. 1) is used to store all radioactive solid waste produced at the Savannah River Plant (SRP) and occasional special Energy Research and Development Administration (ERDA) shipments from offsite. This storage site occupies 80 hectares between the two chemical separations areas at SRP, approximately 9.5 km from the nearest plant boundary. The original area of 30 hectares, which began to receive waste in 1953, was filled in 1972, and operations were shifted to a 50 hectare site contiguous to the original area.

Two phases of surveillance and control are considered for the future of the burial site. The first phase is considered during the life of the plant and for a limited period following plant shutdown. During this time, control and normal surveillance of the site will continue.

The second phase follows for an indefinite period, and requires minimal control and surveillance of the site. Appropriate measures to prepare the burial ground for minimal control are being incorporated into burial ground operation. Criteria for minimal control of the burial site must ensure that long-lived nuclides [^{90}Sr, ^{137}Cs, and transuranium (TRU) alpha nuclides] remaining in the ground will not constitute a hazard to the public. To minimize site control, the following limits have been placed on the quantity of beta-gamma radioactivity emplaced each year at the solid radioactive waste storage site:

^{137}Cs	500 Ci
^{90}Sr	500 Ci
^{60}Co	3×10^5 Ci
^{3}H	4×10^5 Ci
Other nuclides ($T_{1/2}$ >10 yr)	1×10^3 Ci
Other nuclides ($T_{1/2}$ <10 yr)	5×10^5 Ci

The purpose of this study is to validate the current limits for burial of ^{90}Sr and ^{137}Cs and to provide guidance in developing criteria for future surveillance and control of the burial site in the years following the end of plant operation. A mathematical model to simulate movement of radionuclides from buried solid waste through the environment to man is being formulated. Model results will define critical pathways for nuclide transport to man and will estimate projected dose-to-man from buried solid waste.

PRELIMINARY STUDY

A preliminary study has been completed to define possible pathways for ^{90}Sr movement from buried solid waste to man and to estimate the potential dose-to-man. Possible ^{90}Sr routes through the environment are shown in Fig. 2. Each block represents an environmental compartment that may contain strontium. The arrows indicate the direction the strontium moves from one compartment to another. ^{90}Sr in buried waste may move to man through a set of aquatic pathways (ground water, creeks, and river) and through a set of terrestrial pathways (vegetation, animals, and dust).

The direct-contact compartment represents a postulated condition that could occur only if minimal control of the burial site were to cease; e.g., excavation during construction activities or prospecting for scrap.

The rate and extent of movement of ^{90}Sr through the paths of Fig. 2 was estimated based on the following known or assumed parameters:

- 16,500 Ci of ^{90}Sr was in the SRP burial ground December 31, 1976.
- Plant operation will continue until 2000. During this time, 500 Ci of ^{90}Sr will be buried each year (current limit).
- The SRP burial ground will be under surveillance for 100 yr following plant shutdown. During this time, no deep-rooted vegetation will be allowed to grow over the site.
- The SRP burial ground area is about 80 hectares.
- The average depth of the water table is 13.7 m.
- The average rate of downward movement of soil moisture is 2.1 m/yr.
- The average rate of horizontal movement of ground water in the water table is 12.2 m/yr.
- Distribution coefficient (K_d) for strontium on plant soils is 9.
- ^{90}Sr leach rate from the waste is 1%/yr (all of the ^{90}Sr is leachable).

From the above parameters, the following projections were calculated:

- The total ^{90}Sr in the burial ground will be 18,500 Ci in the year 2000 and will decay to 1700 Ci in the year 2100.
- Downward movement of ^{90}Sr through soil is 0.04 m/yr. Strontium will reach the water table in about 200 yr, at which time 99% of the ^{90}Sr will have decayed.
- Lateral movement of ^{90}Sr at the water table is 0.34 m/yr.

By integrating over the entire burial ground, the average rate at which strontium would enter the water table is about 0.8 Ci/yr. This strontium would be dispersed in 3×10^8 L of ground water (if a mixing depth of 1 m and a porosity of 35% is assumed). The maximum strontium concentration in ground water would be about 2×10^3 pCi/L (MPC = 3×10^2 pCi/L). The projected dose to a single individual from drinking water, if farmstead supply wells were located in the burial region in the year 2000, would be about 1.4 rem/yr. The affected population would be small because the shallow water table has a limited capacity sufficient only for household use. Deeper strata, true aquifers such as the McBean formation, are partially protected by clay barriers of low permeability against downward movement from the Barnwell formation (DESWM076).

Ground water beneath the burial ground flows toward Four Mile Creek in a well-defined 0.8-km flow path. At the ^{90}Sr flow of 0.34 m/yr, about 2400 yr is required for ^{90}Sr to reach Four

Mile Creek. During this time, ^{90}Sr would decay by a factor of 10^{-25} to a negligible level. Ground water beneath a part of the burial ground may also flow to Upper Three Runs Creek. The flow path to Upper Three Runs Creek is about the same as that to Four Mile Creek. Essentially no ^{90}Sr would reach either creek. Data from tests now in progress are not yet available, but transfer of ^{90}Sr to deeper aquifers and then to the Savannah River is not expected to be faster than to the creeks. By the year 2100, all of the ^{90}Sr would have been displaced from the waste. If the 1700 Ci remaining are assumed to be evenly distributed, 1.2 to 12 m below grade under the 80 hectare burial ground, the soil would contain about 130 pCi/g, which is about 500 times the ^{90}Sr now in US soil from fallout (Me68).

To project dose-to-man for the terrestrial pathways, data from other locations were reviewed for possible application at SRP. Published data on ^{90}Sr uptake by plants deals with soil contaminated with fallout, which is near the surface. No data relate to deeply implanted (>1.2m) ^{90}Sr. However, studies at Risö (Denmark) (AN67a, AN67b) measured strontium uptake for some food crops grown in soil containing strontium to depths of 85 cm. Table 1 shows the effect of subsurface placement of strontium on uptake by barley. At depths >20 cm, uptake was 1/3 that at the surface.

Projected ^{90}Sr values in selected food items, if they were grown on burial ground soil after the year 2100, are shown in Table 2.

Values are linear extrapolations of the Risö data by assuming that strontium at depths of >85 cm will give the same uptake as that at 85 cm. The value for milk was based on cows grazing on clover, and strontium concentrations in milk were related to that in clover by (Bo71)

$$\mu Ci\ ^{90}Sr/L\ (milk) = 0.002\ (\mu Ci\ ^{90}Sr/kg)\ clover$$

The beef values are derived by assuming cattle would graze on clover (daily forage intake: 10 kg/day), and the strontium content of the meat is related to daily strontium intake by (Bo71)

$$\mu Ci\ ^{90}Sr/kg\ meat = 0.0006\ (\mu Ci\ ^{90}Sr\ intake/day)$$

To estimate projected dose-to-man for a worst case condition, the burial ground was assumed to be used as a farm site. If corn, milk, and beef were grown on the burial ground (Table 2), and if shallow ground water from the burial ground were consumed for a period of 1 yr, the 70-yr bone dose commitments to an individual would be as shown in Table 3. The largest contributor to the total dose is consumption of vegetable crops (i.e., corn) grown on the burial ground. However, the effect of increased depth of placement of strontium on the reduction of plant uptake may have been underestimated. If so, consumption of shallow ground water may be the critical path for dose-to-man.

PROGRAM

To refine dose-to-man projections, a detailed conceptual model of radionuclide transport has been formulated (Fig. 3). A computer program has been written to calculate nuclide transport among the compartments of the model. The program solves a system of linear differential equations of the form

$$\frac{dQ_n}{dt} = \Sigma_{n=1}^{N} \lambda_{n,m} Q_m - \Sigma_{m=1}^{N} \lambda_{m,n} Q_n - \lambda^R Q_n \quad \text{(Bo71)}$$

where:

Q_n represents the quantity of nuclide in compartment N, and Q_m represents the quantity of nuclide in compartment M.

$\lambda_{n,m}$ is the transfer coefficient for the transport of nuclide from compartment m to compartment n, and $\lambda_{m,n}$ is the transfer coefficient for transport of nuclide from compartment n to compartment m.

λ^R represents loss by radioactive decay.

Units for transfer coefficients are $(\text{years})^{-1}$.

Values for transport coefficients will be assigned based on available data. Sensitivity analysis will determine critical pathways for eventual dose-to-man. Evaluation of the critical pathways will provide a basis to establish criteria for future minimal control of the burial site.

Several current and planned experimental programs are designed to refine estimates of model parameters:

Exhumation Tests

- In 1975, a process vessel that had been buried for 18 yr was exhumed (Ho76). Soil samples from the vicinity of the vessel were analyzed for ^{90}Sr, ^{137}Cs, and ^{239}Pu. ^{90}Sr was found to be more mobile than ^{137}Cs and ^{239}Pu.

- Process piping (buried for about 15 yr) will be exhumed. Soil and pipe samples will be analyzed to determine leach rate and soil migration rate of ^{90}Sr, ^{137}Cs, and ^{239}Pu.

Lysimeter Tests

- A set of 32 lysimeters will be installed in the burial ground. Representative waste material such as exhumed process piping, boxed waste, etc., will be buried in the lysimeters. Radionuclides leached from the waste will be collected and analyzed over a period of several years. The leachability of nuclides from buried waste, a key parameter of the migration model, and the effect of saturated or unsaturated soil moisture conditions and vegetative cover on nuclide transport will be determined.

Soil Tests

- Strontium distribution coefficient (K_d) was determined from a set of 56 soil samples from the burial ground. The K_d values were 9 to 6000. The mean was 400 and the median was 110.
- Further tests will define cesium and plutonium K_d values from burial ground soils.

CONCLUSIONS

The preliminary study of ^{90}Sr transport from buried solid waste to man showed that consumption of shallow ground water may be the critical path for dose-to-man in the year 2200. Future work will refine the transport model. Other important pathways will be defined and estimates of transfer coefficients will be improved.

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TABLE 1

EFFECT OF DEPTH ON ^{90}Sr UPTAKE BY BARLEY FROM SOIL CONTAINING 5000 pCi ^{90}Sr/g

Depth of ^{90}Sr, cm	pCi ^{90}Sr/g
0 - 5	280
20 - 25	82
40 - 45	76
80 - 85	100

TABLE 2

PROJECTED ^{90}Sr IN FOODS PRODUCED AT THE BURIAL GROUND

Food	^{90}Sr	Amount to Give Body Burden of 0.3 μCi
Corn	65 pCi/g	4600 g
Milk	0.001 μCi/L	300 L
Beef	3 pCi/g	100,000 g

TABLE 3

ESTIMATED 70-YR DOSE COMMITMENTS FROM ^{90}Sr FROM CONSUMPTION OF FOOD AND WATER PRODUCED ON THE BURIAL GROUND

Food Item	Daily Consumption (NG68)	Dose Commitment, rem
Water	1.2 L	1.4
Milk	1 L	0.5
Beef	300 g	0.5
Corn	100 g	4

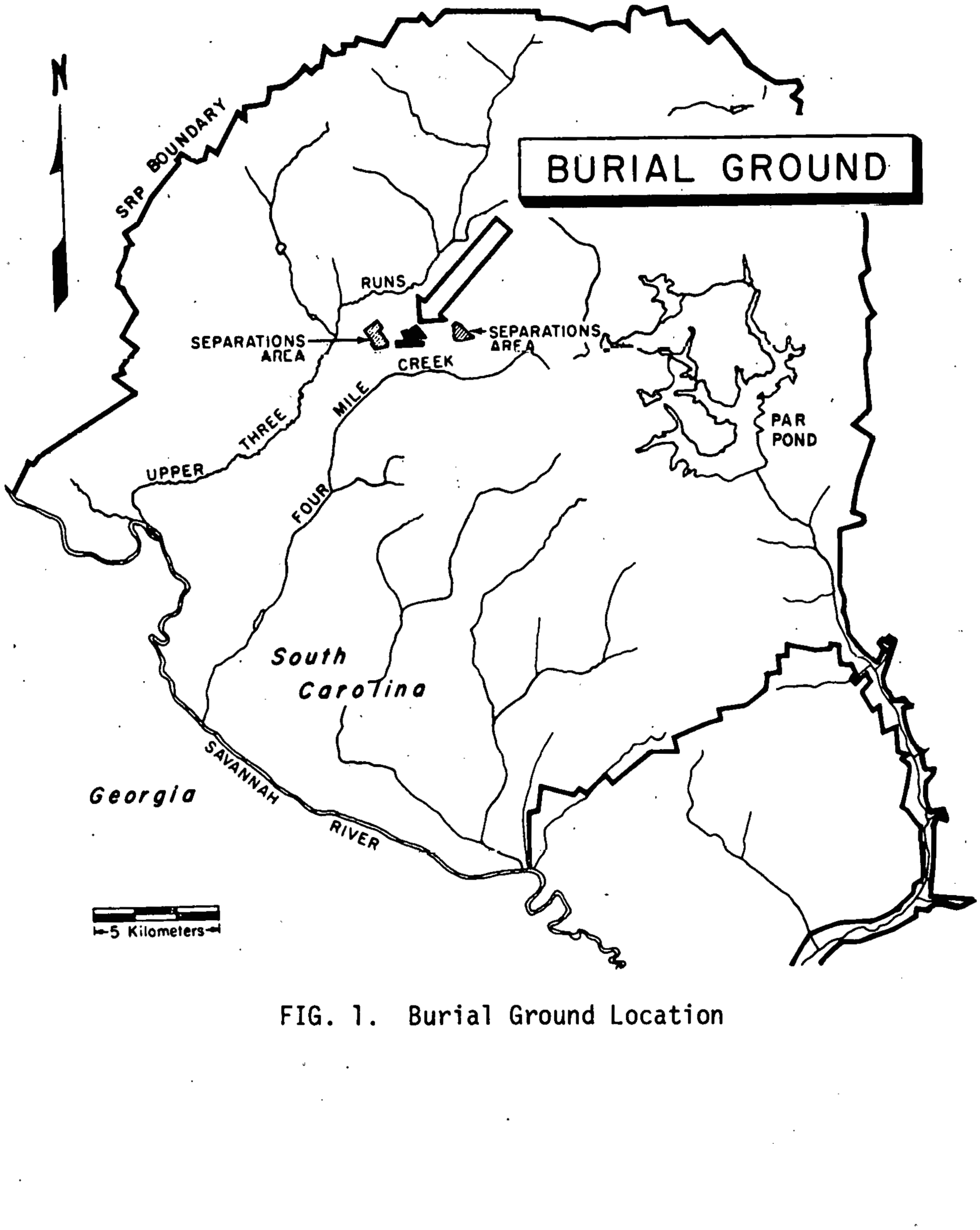

FIG. 1. Burial Ground Location

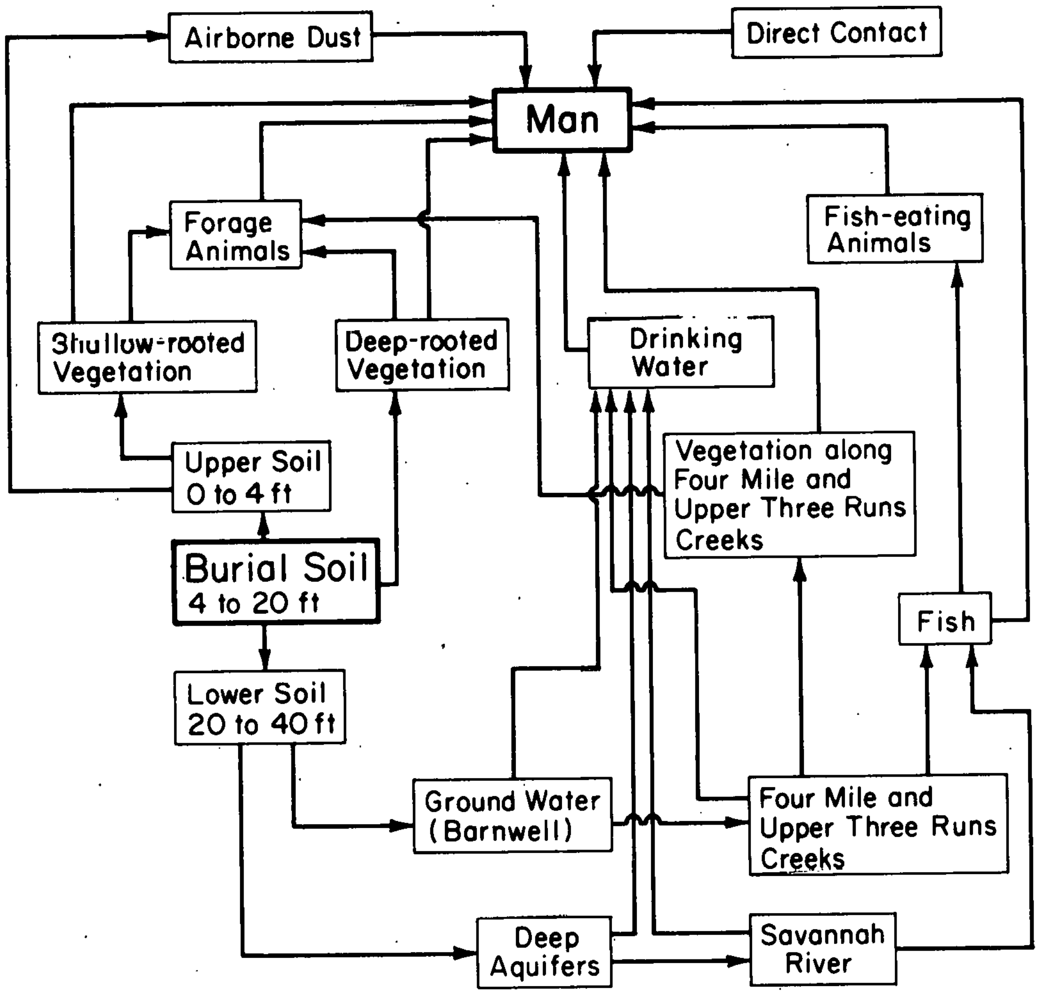

Fig. 2. Preliminary ^{90}Sr Transport Model

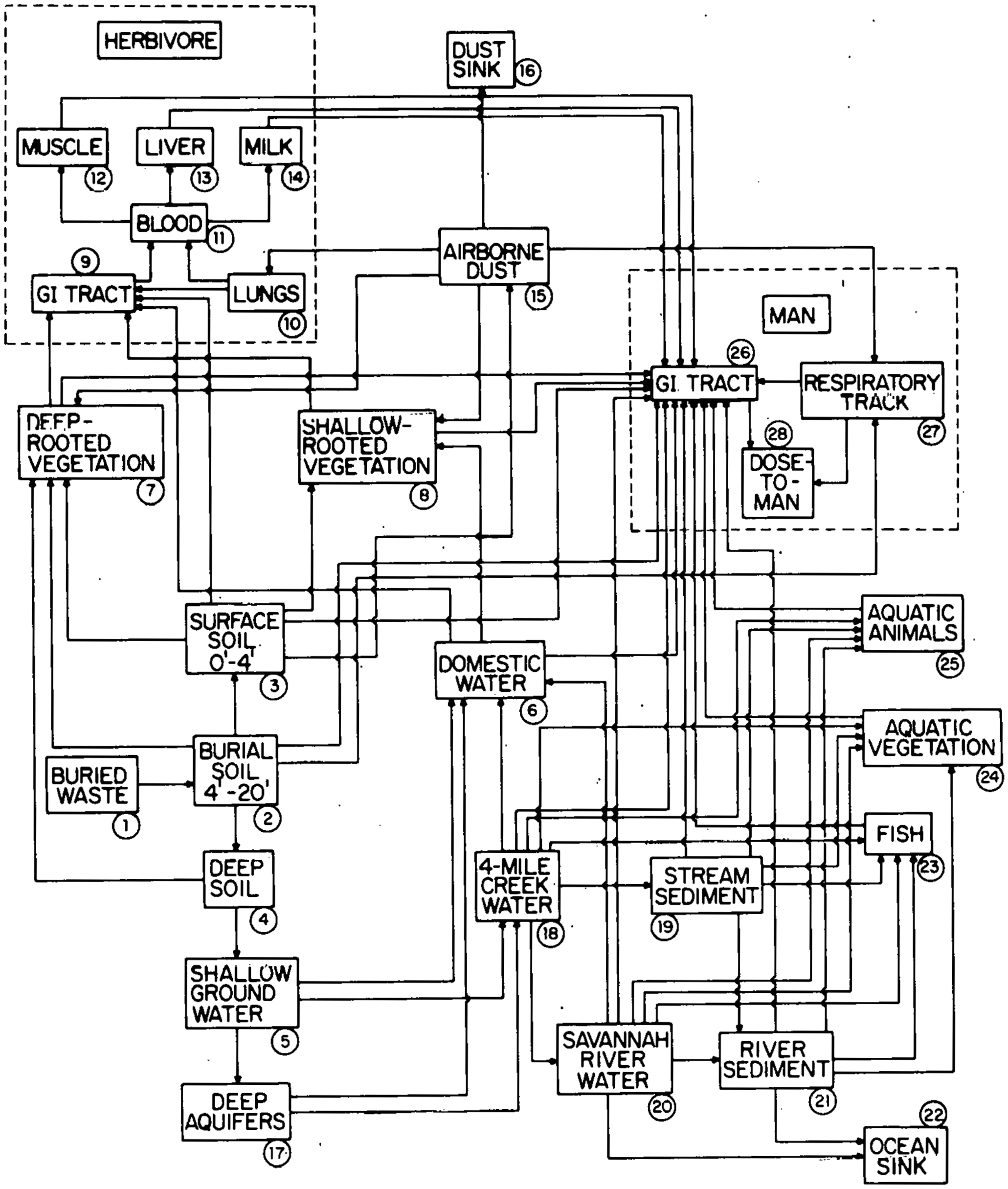

Fig. 3. Radionuclide Transport Model