# GROUND WATER ANALYSIS OF THE PROPOSED LOW-LEVEL RADIOACTIVE WASTE DISPOSAL SITE IN MARTINSVILLE, ILLINOIS

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## ABSTRACT

A two dimensional electrical analog model is used to evaluate the ground water flow at the proposed low-level radioactive waste (LLRW) disposal site in Martinsville, Illinois. The results indicate ground water flow from the site to the biosphere will take at least 500 years by which time radioactive decay has greatly reduced the original activity.

## ELECTRICAL ANALOG

Hydrological systems have been studied by analyzing an analogous electrical circuit (1-3). The major drawback to this method has been the need to create extensive physical electrical circuits which offer very little flexibility. However, using computers an electrical circuit can be evaluated without the need for a physical circuit. Given an input of nodal arrangement, resistor values, and current and voltage sources, the program PSPICE calculates the resulting voltage at each node in the circuit (4,5). Ohm's law is then used to calculate the current between nodes from which it is straight forward to determine the ground water velocity and travel time.

The electrical circuit analogy can be thought of as an approximation of the more rigorous Laplace equation for fluid flow. It is therefore necessary to evaluate each potential site using appropriate boundary conditions. Boundary conditions of the first and second type can be applied to the model. Constant boundary voltages are simulated by attaching voltage sources to the desired nodes. This type of boundary condition is useful when the ground water potential at a boundary is known, e.g. when a river comprises a boundary of the site. Similarly, constant or variable input current can be simulated by attaching a current source at the required nodes. Input current is typically used at the ground surface to simulate ground water recharge.

## THE MARTINSVILLE ALTERNATIVE SITE

Martinsville is a city of 1100 people located in southeastern Illinois. The proposed site, or Martinsville Alternative Site (MAS), is located north of the city which has jurisdiction over the site.

The site is a flat plain with increasing elevations to the north-west. The site is drained and bordered by three small rivers. The Kettering Branch forms the eastern border while the Bluegrass Creek forms the northern border. Both rivers are small and drain into the North Fork Embarras River which forms the western border. The North Fork river and its tributaries are the primary drainage system of the Martinsville region. The southern border of the site is formed by Interstate 70.

The stratigraphy of the site is best demonstrated in Figs. 1 and 2. Figure 1 is an east-west cross section of the site when looking north while Fig. 2 is a north-south cross section when looking west. The main stratigraphic units are the same in both cross sections. The surface layer is composed of several soil types, but for the purpose of modeling this layer will be considered loess. Beneath the loess is a layer of fractured till which lies immediately above a thick layer of Vandalia till. The Vandalia till acts as a confining unit and thus separates the surface water flow patterns from the ground water flow patterns. Beneath the Vandalia till lies the sand facies.

The sand facies is a sand body which extends under most of the site and is confined between two thick layers of till, the Vandalia till above and the Smithboro till below. The Smithboro till, at most locations at the site, lies directly above the bedrock which is itself layers of shale, coal, and sandstone.

A major part of the modeling effort is to determine what effect the sand facies has on the site flow patterns. As a confined aquifer, the sand facies is not dependent on the surface ground water flow. Figure 1 suggests that the sand facies is blocked by a bedrock "knob" just east of the North Fork river. This, however, may not be the case over the entire site and to explore this possibility, the sand facies will be modeled in some cases as a continuous layer. This is a conservative assumption because any connection will allow contaminants entering into the sand facies to be carried to the North Fork Embarras River.

A series of questions about the site's hydrological flow properties must be examined. First, it is necessary to determine the critical flow path which contaminants would take in the event of a leak. Also, the minimum time these contaminants would take to reach the biosphere must be determined. Finally there has been some discussion that the Martinsville city wells may be pumping water from the sand facies resulting in a "cone of depression" around the wells which could extend to the site. As a result, some people fear

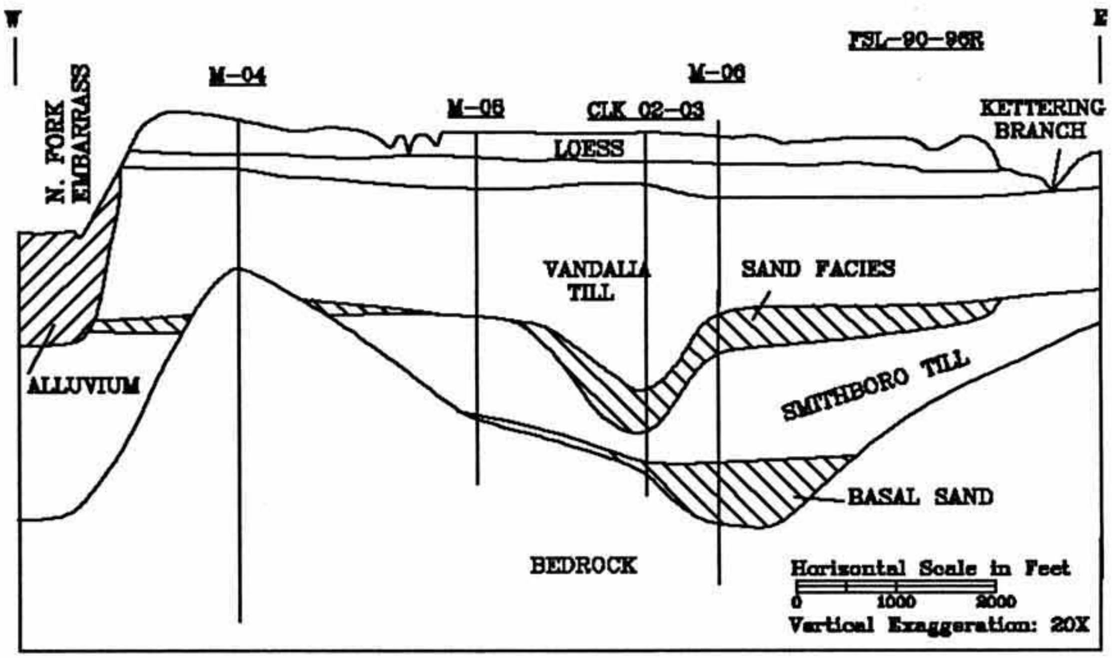


Fig. 1. East-West cross section of the MAS. Note vertical exaggeration.

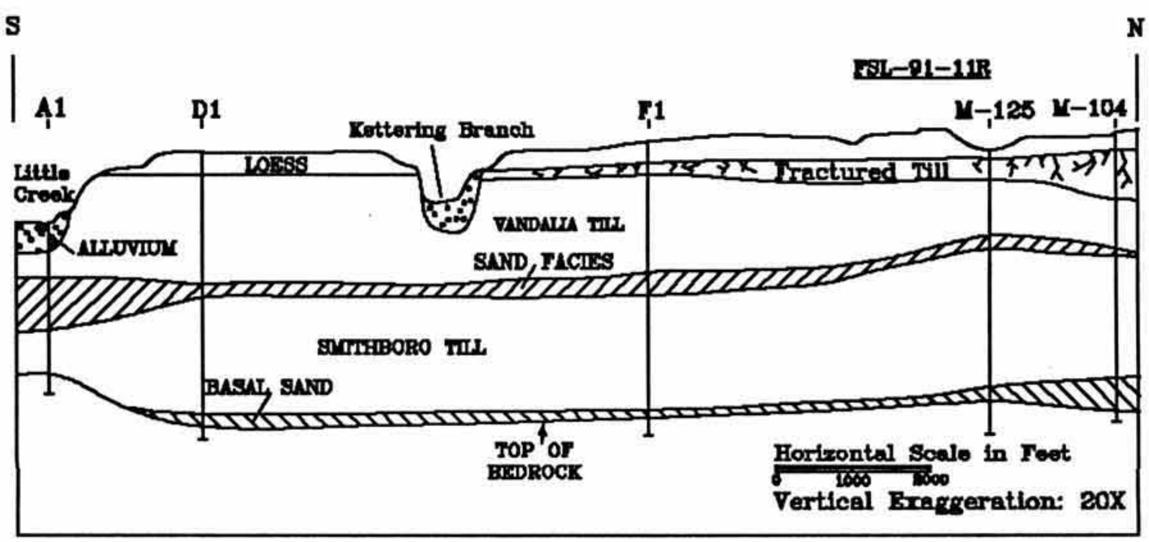


Fig. 2. North-South cross section of the MAS. Note vertical exaggeration.

that the sand facies acts as a conduit which leads contaminants directly into the city water supply.

## MODEL ADAPTATION TO THE MAS

To model the MAS using the electrical analog method, the site stratigraphy is first divided into cells with nodes being at the center of the cells. Resistors between the nodes are calculated as discussed in the Refs. above (1-3). Surface boundary conditions are determined by piezometric measurements and hydrological contouring performed by Battelle Memorial Institute. All other boundary conditions are determined by piezometric head measurements taken at the cells in question. All head measurements are taken relative to the level of the North Fork Embarras River which should have the lowest piezometric head level at the site. As such, the North Fork Embarras River in the electrical analogy is given a zero voltage, that is, it is electrical ground.

## DATA

The data used is determined by exploratory drilling, piezometric head measurements, and hydrological testing performed at the site. Required data includes hydraulic conductivities (6), porosities (7), and piezometric head values (7,8). Table I presents the hydraulic conductivities and porosities used in the base case model.

Due to the variable nature of soil formation and deposition, hydraulic conductivities and porosities are not constant over the site. As a result, average soil porosities for each strata are used in the modeling. It is assumed in the original data that the horizontal hydraulic conductivity (Kx) of each strata is a factor of ten greater than the vertical hydraulic conductivity (Ky). For sensitivity analysis, the model will be run for cases with and without this assumption. To further test the model's sensitivity to hydraulic conductivity, this parameter for all strata will be varied by +/- twenty and fifty per cent as well as an order of magnitude.

## RESULTS

### East-West Primary Cases

The model results can be compared to actual site conditions by comparing predicted and measured piezometric head values. One such opportunity is at the well cluster M-06. One well in this cluster, M-06A, measures the piezometric head level in the sand facies. Readings from this well indicate the piezometric head to be roughly 183m above sea level, or 8.80m above the local level of the North Fork Embarras River. The model predicts that the piezometric head at this node to be 1.37m above the level of the North Fork river when the sand facies is assumed continuous and 7.74m if it is not continuous.

**TABLE I**

Sand Facies Ground Water Velocity Profile.

| Strata | Horizontal Conductivity Kx (cm/s) | Vertical Conductivity Ky (cm/s) | Porosity |
|---|---|---|---|
| Alluvium | $9.98 \times 10^{-3}$ | $9.98 \times 10^{-4}$ | 0.38 |
| Loess | $9.98 \times 10^{-4}$ | $9.98 \times 10^{-5}$ | 0.42 |
| Fractured Till | $1.50 \times 10^{-4}$ | $1.50 \times 10^{-5}$ | 0.20 |
| Vandalia Till | $7.34 \times 10^{-8}$ | $7.34 \times 10^{-9}$ | 0.22 |
| Sand Facies | $2.12 \times 10^{-2}$ | $2.12 \times 10^{-3}$ | 0.19 |
| Smithboro Till | $7.34 \times 10^{-8}$ | $7.34 \times 10^{-9}$ | 0.29 |
| Ionian Silt & Clay | $7.34 \times 10^{-8}$ | $7.34 \times 10^{-9}$ | 0.37 |
| Basal Sand | $3.53 \times 10^{-2}$ | $3.53 \times 10^{-3}$ | 0.29 |
| Bedrock | $1.50 \times 10^{-4}$ | $1.50 \times 10^{-5}$ | 0.20 |

The model is in best agreement with actual conditions when the sand facies is modeled as a noncontinuous body. That is, one primary result of the model demonstrates that there is no effective hydrological connection between the sand facies and the North Fork Embarras River. This can be confidently stated by realizing that nearly any connection between the two would result in a much lower piezometric head than is actually observed. For conservative modeling, however, the sand facies will be assumed to be continuous throughout the site from this point on.

The east-west cross section reveals that the primary flow path is downward percolation through the loess and Vandalia till followed by flow through the sand facies into the North Fork Embarras River. The travel times through each strata are calculated for cases when the horizontal to vertical conductivity ratio is 10:1, BCASE10, and 1:1, BCASE1. The results which are presented in Fig. 3 show that the main impedance to ground water flow is the Vandalia till. The sand facies offers very little resistance to the water's movement, taking less than 3% of the total travel time in each case.

The velocity profile through the sand facies for both cases is shown in Fig. 4. In the base case scenario with a 1:10 conductivity ratio the maximum velocity along the sand facies is determined to be 26.0 m/year while the velocity under the site is roughly 5.50 m/year. The maximum velocity in the sand facies is increased, however, if the conductivity ratio is not assumed to be 10:1. For example, using a conductivity ratio of 1:1 the maximum velocity is 103 m/yr while the velocity directly under the site is 32.5 m/yr.

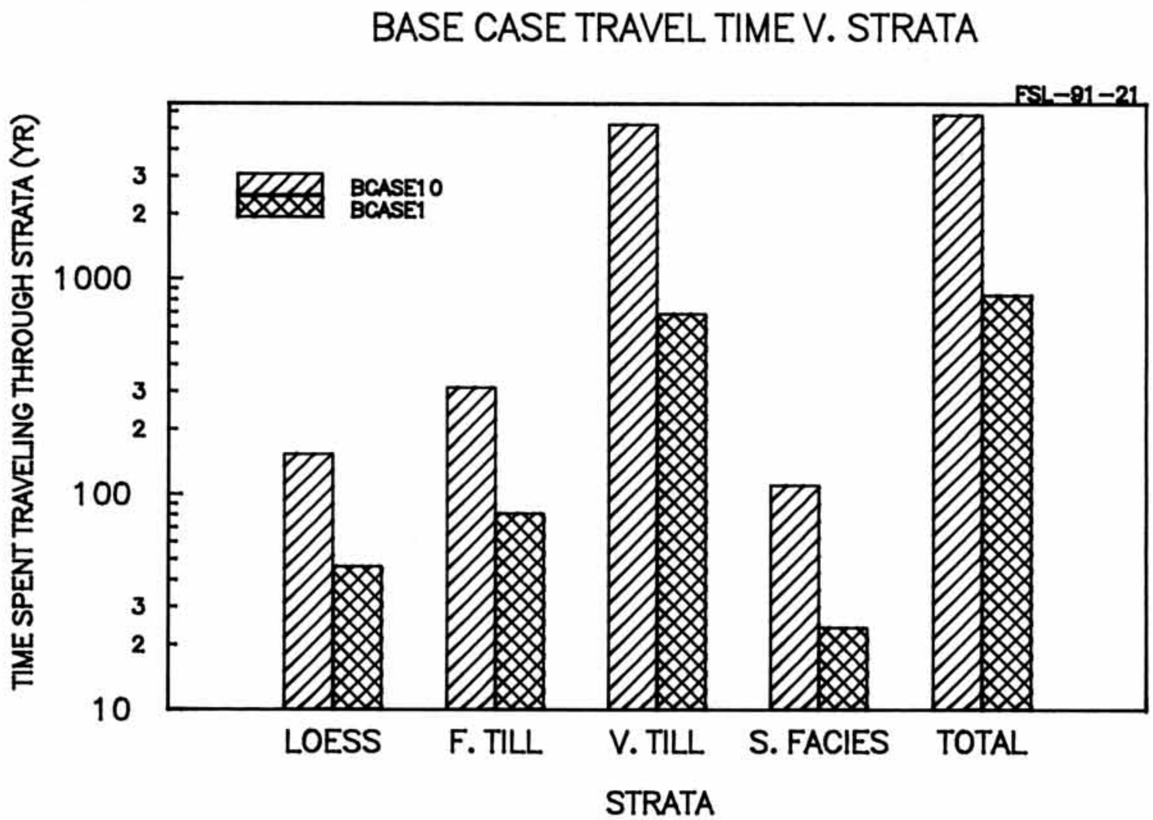


Fig. 3. Ground water travel time by strata.

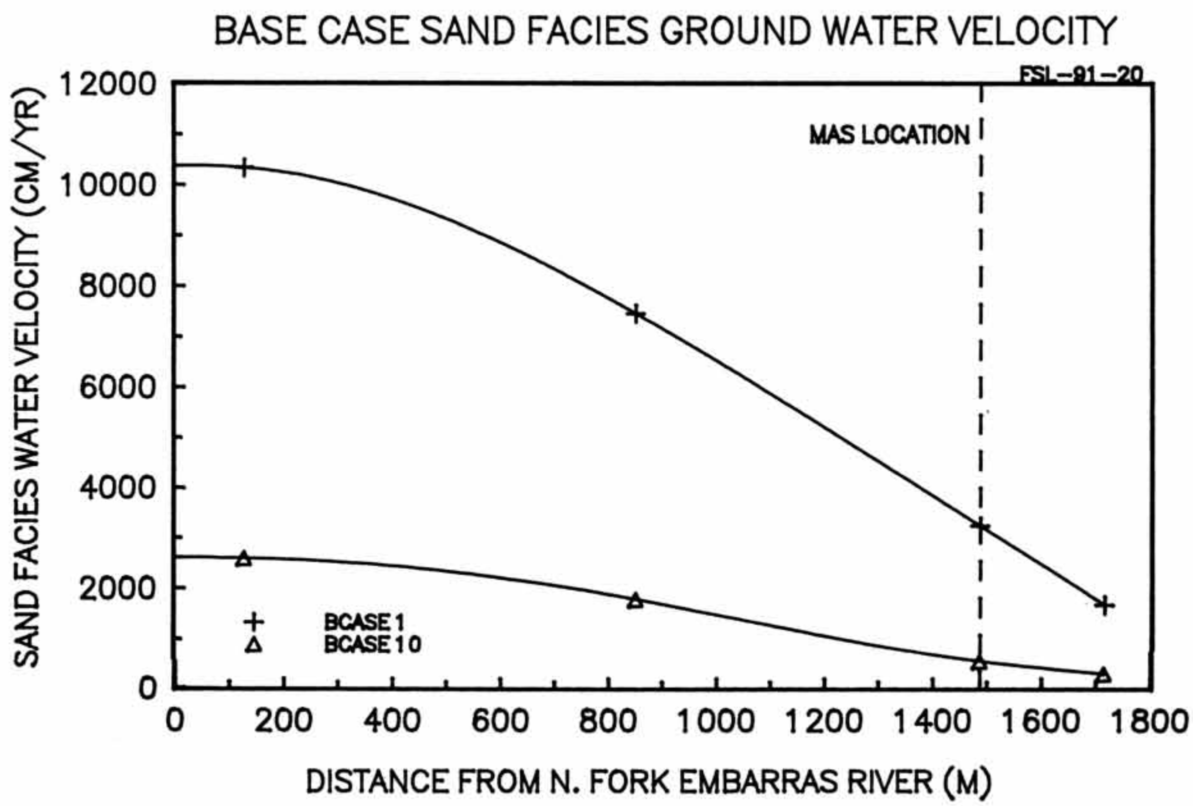


Fig. 4. Ground water velocity through the sand facies.

The large difference in both total travel time and velocity through the sand facies between these two cases can best be understood using the electrical circuit analogy. In the case of 1:1 ratio, there is less resistance to downward water flow, therefore more water travels in this direction and requires less time to reach the sand facies. The increased volume flow into the sand facies in turn requires that the water travels faster through the sand facies towards the North Fork Embarras River.

East-West Sensitivity Analysis

It is important to know the sensitivity of the model to perturbations in parameter values in order to realistically estimate errors in the model predictions. The parameter which most influences ground water flow patterns is the hydraulic conductivity. Therefore, the hydraulic conductivities of each stratum are varied from the base case conductivity values by +/- 20 and 50 percent. In order to estimate the effects of large variations in conductivity data, the same procedure was repeated with conductivity values varied by an order of magnitude. Finally, for each of these, a case assuming 10:1 and 1:1 conductivity ratio is performed.

Table II indicates that varying the hydraulic conductivities changes velocities and travel times dramatically. As expected, the "worst case" scenario is that in which the hydraulic conductivities are the highest and when the horizontal to vertical conductivity ratio is 1:1. In this case, the total travel time required for water at the site to reach the biosphere is only 78 years. This case should be viewed skeptically since it requires that hydraulic conductivities at the site are vastly different than the field tests indicate. This is also the only case in which the travel time is less than the 500 year retention time goal for the disposal facility.

North-South Cases

The primary interest in the flow patterns at the site in the north-south plane is to determine the effect pumping at the Martinsville city water wells has on the ground water beneath the site. Some people are concerned that the pumping draws water from beneath the site creating another pathway to the biosphere.

To investigate this, a pump was simulated in the model by drawing current via a current source from the circuit. The current source is attached to the sand facies node where the exploratory well A-1 is located in Fig. 2. This roughly corresponds to the position of the Martinsville city water wells. The piezometric heads throughout the sand facies can then be predicted by the model. Once validated, travel times from the site to the well are calculated.

The model is able to predict the sand facies piezometric head at wells F-1 and M-125 to within 1.25m but fails to model the conditions at well D-1 accurately (actual and predicted values are 176.5m and 164.6m above sea level respectively). The reason for this discrepancy is not readily apparent.

**TABLE II**

Ground Water Travel Time from the MAS Location to the North Fork Embarras River Broken Down by Strata

| Strata | +20% 10 | +20% 1 | -20% 10 | -20% 1 | +50% 10 | +50% 1 |
|---|---|---|---|---|---|---|
| Loess | 130 | 40 | 190 | 60 | 20 | 30 |
| Fract. Till | 90 | 70 | 390 | 100 | 180 | 40 |
| Vand. Till | 4320 | 590 | 6510 | 860 | 3400 | 430 |
| Sand Facies | 100 | 20 | 140 | 30 | 100 | 20 |
| Total | 4640 | 720 | 7230 | 1050 | 3700 | 520 |

| Strata | -50% 10 | -50% 1 | *10 10 | *10 1 | /10 10 | /10 1 |
|---|---|---|---|---|---|---|
| Loess | 570 | 150 | 10 | 5 | 1540 | 460 |
| Fract. Till | 520 | 110 | 30 | 7 | 2610 | 540 |
| Vand. Till | 10400 | 1200 | 500 | 62 | 62100 | 6500 |
| Sand Facies | 240 | 50 | 20 | 4 | 1050 | 300 |
| Total | 11730 | 1510 | 560 | 78 | 67300 | 7800 |

*Table headings correspond as follows: +20% 10 indicates all hydraulic conductivities are changed by plus 20 per cent and the ratio of horizontal to vertical conductivities is 10:1 whereas the heading /10 1 indicates all hydraulic conductivities are decreased by a factor of ten and the ratio of vertical to horizontal conductivities is 1:1.

Ground water travel time calculations indicate a total travel time of 6580 years from the surface at well M-104 to the sand facies at well A-1. Of this, 6550 years are spent traveling downward from the surface to the sand facies and 30 years are spent traveling through the sand facies. The average sand facies velocity is calculated as 10.7m/yr.

### Contaminant Transport

Key results from the above calculations are shown in Table III. Table III presents the most abundant LLRW isotopes shipped by Illinois for disposal in 1987 (9). The table also shows the activity expected after the fifty year operating life of the disposal facility neglecting any radioactive decay during that time. The maximum resultant activity expected at the biosphere if all this activity were released from the site is also demonstrated. This is presented for the cases previously explained which have the shortest travel times.

During the time required to travel to the biosphere nearly all of the original activity will have decayed. This is especially pronounced when considering Co-60 which comprises most of the original activity. In all but the most extreme cases, the Co-60 activity has decayed completely before exposure to the biosphere. Other isotopes, such as C-14 and Tc-99, decay relatively little during the travel time but are present in smaller quantities.

This analysis neglects several factors. First, an unrealistic scenario is assumed in which all activity is released in a single incident at the end of the facility's operational life. Second, no correction is made for dilution of the radionuclides by the ground water. Third, retardation of contaminants by the clayish Vandalia till is neglected. Finally, decay of the radionuclides during the time spent at the facility is omitted. The resulting activity to the biosphere would be exceedingly small if all the above factors are considered.

## CONCLUSIONS

The results of the model indicate that there is not an effective hydrological link between the sand facies directly under the site and the North Fork Embarras River. In addition, flow from the site to the city through the sand facies is calculated to take 6600 years. This is far beyond the design life of the facility. Finally, conservative calculations of the activity expected after traveling through the soil indicate that all but the most-long lived isotopes have significantly decayed.

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**TABLE III**

Activities in Curies which Reach the North Fork Embarras River after a Release Equivalent to Fifty Years Accumulation of LLRW.

| Isotope | Original Activity | BCase 10 | BCase 1 | +20% 1 | +50% 1 | *10 1 |
|---|---|---|---|---|---|---|
| Am-241 | 3 | --- | 1 | 1 | 1 | 3 |
| C-14 | 733 | 364 | 663 | 673 | 689 | 727 |
| Cs-137 | 2.04E4 | --- | --- | --- | --- | 3500 |
| Co-60 | 6.91E8 | --- | --- | --- | --- | 2.88E4 |
| H-3 | 655 | --- | --- | --- | --- | 9 |
| Pu-241 | 354 | --- | --- | --- | --- | 9 |
| Sr-90 | 279 | --- | --- | --- | --- | 43 |
| Tc-99 | 147 | 144 | 146 | 146 | 147 | 147 |
| U-238 | 50 | 50 | 50 | 50 | 50 | 50 |
| TOTAL | 6.91E8 | 558 | 860 | 870 | 887 | 3.33E8 |

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