CONSIDERATION OF ALTERNATIVES REGARDING SHALLOW LAND DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTE FOR A DEVELOPING COUNTRY*

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ABSTRACT

The Turkish Atomic Energy Authority (TAEA) is developing plans for improved control of low-level wastes (LLW) in Turkey. The present generation rate of radioactive waste in Turkey can be compared to the early days of the United States,[1-3] i.e, waste is principally generated in hospitals, biological research centers, universities, and industry. Because the volume of the waste is small, most institutions dispose of their waste. Storage and incineration are the methods of management for the existing wastes.

Since Turkey is in the process of planning two nuclear power reactors, the TAEA strongly believes that there is a definite need for a comprehensive regulation for the disposal of the LLW.[4] Through the Internal Atomic Energy Agency (IAEA), the TAEA is planning to obtain this regulation. We are preparing technical discussions for TAEA's consideration in drafting a regulation. Our effort seeks to avoid the mistakes in the LLWD history. The initial step is to draft and enact a suitable set of regulations consistent with the state-of-the-art in technical developments and tailored to meet the specific institutional and technical needs of Turkey. The major points of the proposed regulation are General Provisions, Licenses, Performance Objectives, Technical Requirements for Disposal Facilities, Financial Assurances, and Records, Reports, Tests, and Inspections.[5-7]

Recently, a Western European country approached TAEA regarding sending their LLW to Turkey for disposal.[4] This certainly has added another dimension to the LLWD efforts of TAEA. If accepted, much needed technology as well as financial support may be directed to Turkey with the LLW of some of the European nations. With this new dimension, LLWD within Turkey becomes a unique international issue.

In this study, we discuss application of two screening methodologies to develop estimates of human exposure and health risks from shallow-land burial of low-level wastes in central Turkey. The first methodology is a conservative approach based on a limited number of assumptions. This simple methodology implemented in BASIC on an IBM personal computer, provides bounding estimates of maximum human doses that might result from ingestion of contaminated groundwater. One may rapidly obtain rough estimates of the effects of disposing of additional radionuclides at the site, of modifying the waste form to effect the release factor, or of diluting the released leachate into different volumes of uncontaminated water. We have examined the consequences of disposing of three waste streams in the proposed waste disposal area. These streams are pressurized water reactor ion exchange resins, pressurized water reactor compressible trash, and institutional liquid scintillation waste, and assume a distribution of 23 radionuclides developed in US Nuclear Regulatory Commission Analyses.[7]

The second methodology is much more versatile, and explicitly considers percolation of surface water downward into a trench, leaching of radionuclides, vertical and horizontal radionuclide transport at a retarded velocity, and use of contaminated groundwater and contaminated surface water for farming, irrigation, and ingestion. Ponding of water in trenches, leachate overflow, cap erosion, and radionuclide suspension and transport by winds are also considered. Rather than implement our own version of such a methodology, we have chosen to apply the PRESTO-II methodology.[8] This methodology is based on US Nuclear Regulatory Commission and US Environmental Protection Agency procedures, and has been applied to several existing and proposed shallow-land disposal areas. We believe that basing the proposed Turkish standards and practices on existing and well-documented methodologies and regulations will best serve the interests of this developing nuclear state.

A SIMPLE, CONSERVATIVE SCREENING MODEL

A simple, conservative methodology has been implemented on a microcomputer and used to estimate maxium doses to at-risk individuals for a selected site in Oak Ridge, Tennessee[7]. This methodology will be used to obtain a preliminary estimate of maximum doses for selected release and exposure scenarios associated with LLW disposal in Turkey. It will also be used to identify nuclides and scenarios that must be considered more carefully. The methodology is implemented in the BASIC language and runs rapidly, thereby allowing different assumptions to be readily and inexpensively considered.

Mechanisms considered explicitly in this methodology include radioactive decay, release factor, and dilution of waste leachate subsequent to release but prior to human exposure. Actual site data are used when available[10]. Dose conversion factors from ICRP-30 [11] are used to convert annual radionuclide ingestion values to 50-y committed effective dose equivalent values.

For this simple calculation of possible individual doses, certain considerations are neglected. No consideration is made of additional leachate dilution en route to a well. No consideration is made of retardation of radionuclides by chemical exchange with soil or other waste material. If this consideration is made, it would be appropriate also to examine the consequences of the inclusion of complexing and chelating agents. No explicit consideration is made of daughter ingrowth prior to ingestion of the parent radionuclide, although this mechanism may be considered by the user and an appropriate daughter activity added to the data set for evaluation. No consideration is made of radionuclide recycling within the watershed. Finally, no account is taken that an individual might drink well or river water during each of several years and thereby accrue a larger dose commitment.

A COMPREHENSIVE SCREENING MODEL

In order to quantitatively consider certain release/exposure scenarios either identified as interesting using simple model described above, or beyond the scope of a simple model, we expect to perform simulations of the consequences of LLW disposal in Turkey using a more comprehensive methodology. A select group of radionulcides will be chosen and several exposure scenarios will be selected, based on the results obtained with the simple methodology described above. We expect to apply the PRESTO-II model and computer code for these simulations.

The PRESTO-II model[8] is an implementation of the PRESTO methodology that was developed in 1983 for the Environmental Protection Agency (EPA). The model has been applied to several LLW disposal sites, and has been used to examine whether it might be possible to set exempt concentrations of certain waste streams that would insure that no more than de minimis doses would be expected[9]. We will describe the PRESTO-II model and discuss its applicability to Turkish LLW sites.

The U.S. Environmental Protection Agency is responsible for developing a generally applicable environmental standard for the disposal of low-level radioactive waste (LLW). A methodology was developed to assist in assessing the potential human health impacts from such operations. This methodology was called PRESTO (Prediction of Radiation Effects from Shallow Trench Operations)[12]. Documentation for Version 2.3 of the PRESTO-EPA model was delivered to EPA in April, 1983, and the EPA is continuing to develop and document versions of the PRESTO-EPA code[13].

PRESTO-II differs from PRESTO-EPA in the following respects:

- PRESTO-II contains what may be a more defensible approach for computing infiltration through the trench cap. The input data-intensive calculation of trench-cap infiltration used in subroutine INFIL of PRESTO-EPA has been replaced by a simpler approach that computes this important variable from experimentially determined permeability and hourly precipitation values. Still other approaches to infiltration have been added as options: (1) use of yearly precipitation values; (2) user-specification of infiltration; and (3) estimation of trench cap infiltration as a fraction of calculated watershed infiltration. All of these methods provide values for infiltration through an intact trench cap — infiltration through failed portions of the cap is computed in a separate calculation.

- Watershed infiltration, an important variable for determining radionuclide weathering from the surface soils, is determined in PRESTO-II using a parametric evapotranspiration equation devised by Morton[14,15]. This model requires input values for the following site variables: annual precipitation, mean sea level pressure, latitude, monthly dew point, monthly ambient air temperatures, and the observed fraction of maximum monthly sunshine.

  According to Morton, this evapotranspiration model has been verified over a wide range of climates and reasonable estimates of water balance have been obtained for 122 river basins on three continents. Wallace[16] reports the Morton model to be superior to both the Thornwaite-Mather[17] and Penman[18] approaches to modeling evapotranspiration in certain environments.

- The computation of trench water balance (including water level, water overflow, and water percolation through the trench bottom), is made using a finite element approach in the PRESTO-II code. In comparison, a finite difference approach with a one-year time step is used in the PRESTO-EPA code. The advantages of the finite element approach are that unphysical predictions of trench overflow are avoided in wet years, and that the time-averaged vertical extent of the saturated zone within the trench is available for use in other calculations (such as those determining radionuclide leaching and contaminated water release from the trench).

- A streamlined algorithm for describing radionuclide transport through subsurface pathways is used in the PRESTO-II code. The calculation of a correction factor for the combined effects of dispersion and radioactive decay used in the PRESTO-EPA code was not used in PRESTO-II. This correction factor differed from unity only in some scenarios in which the magnitude of human exposure was small.

- Additional user options for routing of contaminated water have been implemented in PRESTO-II. For example, contaminated aquifer water that is not pumped from the aquifer at the well may be routed to surface streams.

- The PRESTO-II code has profitted from the discovery of several errors in early versions of the PRESTO-EPA model. These errors have been found and corrected in many cases through joint efforts by ORNL and EPA researchers.

Applicability of PRESTO-II

PRESTO-II is a computer code developed to estimate possible health effects from operations at LLW disposal sites. As an initial condition, up to 40 radionuclides may be specified according to the mass of each radionuclide present on the soil surface, in the air, in a local stream, or in a trench. As presently structured, the code can be used to make estimates for a period of up to 1000 years. The code is intended to be as generic as possible. Most of the transport methodology is derived from previously published work (e.g., Ref. 19). Different transport mechanisms may be considered, but there has been no intent to tailor the code to a particular site. Nevertheless, the assumption in the PRESTO methodology of saturated hydrologic transport results in the prediction of more rapid radionuclide transport than would actually occur at some arid sites. In most cases, the model results are conservative for such sites. The DARTAB model[20] is used in modified form as an important module of PRESTO-II to generate human health-risk estimates from radionuclide concentration and intake values. Cancer risks are calculated for individuals or populations over the assessment period using a life-table approach developed by EPA[21]. Internal dose conversion factors are taken from ICRP 26[22] and 30[11], while risk conversion factors are values suggested by EPA.

The PRESTO-II code construction is modular to allow alternate submodels or subroutines to be substituted if necessary. Many of the submodels included in PRESTO-II were developed for other types of assessments and have been adapted for use in estimating health effects from shallow land disposal of LLW.

The PRESTO-II model is most appropriately used as a screening model capable of considering a variety of release and exposure scenarios, and site specific codes should be considered in cases where PRESTO-II numerical results fall close to reference values used for decision making. The model may be used to estimate doses to populations as an aid to the ALARA process. It may also be used to estimate doses to maximally exposed individual members of the public by specification in the input data that the location of the individual and of the well, used for obtaining water for drinking, crop irrigation, and livestock watering, is at the site boundary. The code contains algorithms to track both radionuclide amounts and radionuclide concentrations in well water. Radionuclides are first withdrawn from the well for human ingestion in an amount appropriate for the number of exposed persons specified, and remaining radionuclides may be withdrawn to be used for irrigating crops and watering livestock. A second reason to account for both amount and concentration of radionuclides at the well is to insure that the amount withdrawn at the well (based on the calculated concentration at the well) does not exceed the amount available. As a result of this calculation, the dose and risk calculated for a single individual may exceed the dose and risk calculated for individual members of a large population taking water from a well.

Humans may also be exposed to radionuclides transported from LLW sites by atmospheric processes. Radionuclides left on the soil surface by trench overflow, by spillage during disposal operations, or by complete removal of the trench cap may be suspended in the atmosphere[23] and transported downwind where they may be inhaled or deposited on vegetation and soil. In the case of deposition, the radioactivity may produce external exposure to humans or may enter into the food chain and result in radioactivity in crops, meat, and milk.

Use of PRESTO-II to calculate population doses for considerations of ALARA, or to calculate maximally exposed onsite or offsite individual doses for consideration of compliance with maximum exposure regulations, is determined by the user's choice of population size, well location, and other input option values and parameters.

The code allows the user to select human exposure scenarios including: migration of radioactivity from the trench in hydrologic and atmospheric environmental pathways to food and drinking water, the presence of a resident intruder on the site, and farming of the site. Processes considered in calculating individual or population exposure include: groundwater transport, precipitation runoff, trench water overflow and seepage, chemical exchange, trench cap erosion, stream dilution, and resuspension and atmospheric dispersion of contaminated soil followed by inhalation or deposition on crops and land.

The termination of LLW disposal operations (as associated with final trench closure) is the starting time for the total assessment period considered by the code. The user specifies the total length of the assessment period, from 1 to 1000 years. The health effects for a user-specified length of time within this assessment period are calculated. The averaging time for health effects can be as short as any single year of the assessment period or as long as the entire assessment period. The maximum concentration of each radionuclide and the year of this maximum for each of the four major exposure pathways for each nuclide is calculated. The initiation time and period for mechanical suspension of the surface soil by farming is specified by the user. The user can also specify the time at which the trench cap begins to fail and the temporal profile of this failure, which results in exposure of the trench contents. The code time step is fixed at one year.

The resident intruder scenario assumes that an intruder digs into the disposal trench while building a residence. The individual will receive external exposure to the buried radionuclides due to time spent in the basement of the residence, which is assumed to have walls made of trench material. The user-specified length of residency, time in the assessment period when the residence is first occupied, and the composition of the initial trench inventory will all contribute to the dose from external exposure.

Farming the site after loss of institutional control is treated as a separate intrusion scenario. By farming the site a farmer will be affected by most of the hydrologic and atmospheric transport processes described above. In contrast to an off-site population, however, a largion portion of the farmer's food may consist of crops grown in the contaminated zone near the trench. The water used by the farmer for irrigation, drinking, and livestock may be taken from directly beneath the trench or from a nearby stream and thus contain a much higher concentration of radioactivity than water used by the off-site population. The farming process may also mechanically suspend contaminated soil in the atmosphere. Such mechanical suspension may impact both the farmer and a downwind population.

Annual-average concentrations of each radionuclide in environmental media (such as well water or the atmosphere) over the assessment period are used to calculate radionuclide concentrations in foodstuffs. Foodstuff information and human ingestion and breathing rates are utilized to calculate the annual average radionuclide intake per individual in the population by ingestion and inhalation. These intake data are used by the exposure and risk submodels to estimate dose rate and health risk.

The health risk estimation methodology assumes that each member of the population is a member of a cohort that is exposed to constant, annual-averaged radionuclide concentration levels. For atmospheric transport calculations, the total population is assumed to reside within the same 22.5-degree sector. User-specified parameters give the fraction of the year that the wind blows into that sector. A user option allows the results of the atmospheric dispersion calculation in the code to be replaced by an externally calculated dispersion coefficient which considers several population centers. Each member of the population is assumed to eat the same quantities of food (vegetables, beef, and milk). These foods are assumed produced on the same fields and spray irrigated with contaminated water. Contaminated water is assumed drunk by beef and dairy cattle. The code user may independently specify the fractions of water taken from wells or streams and used for human consumption, for irrigation, or for livestock consumption.

To assist the PRESTO-II user in compiling radionuclide data, a radionuclide Daughter Inventory Generator (DIG) computer code has been written[24]. This code facilitates the construction of the site inventory radionuclide data set for the PRESTO-II code. The DIG code accepts a table of radionuclide names and amounts initially present in a waste stream and produces a tabulation of radionuclide names and amounts present after a user-specified elapsed time. This resultant radionuclide inventory characterizes wastes that have undergone radioactive decay and daughter ingrowth before leaching and transport, thus identifying daughter radionuclides that should be considered for inclusion in the pollutant source term. The output of the DIG code also includes radionuclide decay constants, which are required in the PRESTO-II code input data set.

A second code has also been written to assist the user in preparing PRESTO-II data sets. This second code is PRESTO-PREP[25]. The PRESTO-PREP code accesses radionuclide data bases to prepare a radionuclide data set in the proper format for reading by PRESTO-II.

Concluding Remarks

The TAEA has promised to send data describing sites proposed for future LLW operations in Turkey. We are establishing cooperative relationships between interested parties to facilitate performing simulations of LLW transport and possible human exposure at these proposed sites. Two methodologies have been identified as being valuable for these simulations. We expect that the results of these simulations will be useful in providing estimates of the consequences of alternative disposal practices.

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