Considerations for Improving the Biosphere Assessment Methodology and the Associated Conceptual and Mathematical Models for Application to LLW/ILW Radioactive Wastes in Spain – 15194

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ABSTRACT

We give consideration to future needs in assessment studies relating to the disposal of very low level radioactive waste (VLLW), low level radioactive waste (LLW) and intermediate level radioactive waste (ILW) in Spain. As these wastes are primarily disposed at El Cabril, particular attention is given to the characteristics of that site.

The focus is on post-closure performance assessment studies and specifically on the biosphere aspect of those studies. In particular, it gives consideration to the assessment methodology that should be used, taking into account the recommendations made in the international BIOMASS and BIOCLIM programs, as well as more recent developments. It then goes on to consider the conceptual models of the biosphere that should be developed and comments on how these should be transformed into mathematical models. The issues arising in conceptual and mathematical model development are illustrated by reference to El Cabril, but several of these issues would also be applicable to other engineered facilities excavated from the surface in a variety of geographical and geological contexts.

INTRODUCTION

Long-term safety assessments for the disposal of radioactive waste in Spain involve the demonstration that annual radiation doses to humans due to potential releases of radionuclides from different waste disposal facility into the biosphere will satisfy the regulatory criteria. For several years, CIEMAT has been developing, for ENRESA, a conceptual approach and tool to support modeling of the migration and accumulation of radionuclides in environmental media once those radionuclides have been released to some component of the biosphere [1]. The CIEMAT modeling approach calculates the concentrations of radionuclides in different components of the biosphere and then the calculated radionuclide concentrations are used to estimate the radiation doses to humans due to various exposure paths. In this paper, we not only outline the methodology and modeling approach, we also describe recent developments of that approach to better quantify the resultant doses to humans.

As well as describing the modeling approach and recent achievements arising from its application, we also present planned work to be undertaken both as the national program develops and also through participation in various international projects that facilitate the exchange of information and sharing of knowledge with other specialists involved in radioactive waste management programs. This international dimension is illustrated by our participation in the working group on Waste Disposal Facilities in the MODARIA project of the IAEA [2] (and in various working groups of the international forum BIOPROTA [3]. In the context of our national program, we discuss future needs and recommendations for assessment studies relating to the disposal of Very Low Level radioactive Waste (VLLW), Low and Intermediate Level radioactive Waste (LILW) in Spain. As these wastes are primarily disposed at El

Cabril, particular attention is given to the characteristics of that site.

EL CABRIL FACILITY

El Cabril is the installation used for the disposal of low and intermediate level radioactive wastes in Spain. It is designed to cover all the current disposal needs for these types of waste, including those arising from the dismantling of nuclear power plants. However, El Cabril accepts only radioactive wastes with a half-life of less than 30 years or wastes with very low levels of long-lived radioactive substances.

The facility is located in the hills of the Sierra Albarrana, in the province of Córdoba, and its history as a waste disposal facility dates back to 1961, when the Nuclear Energy Board transferred the first drums of radioactive waste to the site, disposing of them in a disused uranium mine that is located nearby. However, operation of the current facility for LLW and ILW disposal began in 1992 and operation of the complementary disposal facility for VLLW began in 2008.

The facility has two platforms for the disposal of LLW and ILW and another with specific structures for VLLW. In addition, the facility has the resources required for the treatment and conditioning of those wastes that require such processes subsequent to their receipt at the site.

The El Cabril disposal facility has two functionally differentiated areas: the buildings area and the disposal area (with the disposal system being based on the incorporation of natural and engineered barriers to isolate the materials disposed). This separation allows for the efficient performance of the activities of the center, facilitating their monitoring and control, and differentiating radiologically regulated zones from other areas.

The buildings area has two laboratories for verification of the quality of the wastes. Also located here are the conditioning buildings, in which the waste treatment activities are performed, and the control room, where all the information on operation of the facility is handled. The LLW and ILW disposal zone is formed by two platforms: the north platform, which includes 16 disposal cells, and the south platform, which has 12 such cells. The VLLW disposal zone is formed by a platform to be made up of four structures that will be constructed as they are needed.

The LLW and ILW generated at any location in Spain arrive at El Cabril is unloaded at a conditioning building or one of the temporary storage facilities. Most of these wastes, generated at the nuclear power plants, are already conditioned on arrival, whereas those coming from hospitals, research centers or industries are treated and conditioned at El Cabril.

The waste drums that are received are placed in concrete containers with a capacity of 18 220-litre drums. When a container is full, its drums and their contents are immobilized by means of injected mortar. The compact block is placed in the disposal cell, which is a structure of reinforced concrete. Once the disposal cell is filled with 320 containers, the upper reinforced concrete closure slab is constructed and weatherproofed. Each of the 28 disposal cells has a sump connected to the seepage control network located beneath the platforms. This allows possible in-leakages of water to be detected and, if they occur, to be repaired.

Once the capacity of the platforms has been reached, they will be covered with a final cap consisting of various layers, the last of which will be of topsoil, allowing for integration into the environment. From that time, a 300-year site surveillance and control phase will begin.

VLLW comprises solid materials, generally scrap and rubble, that are minimally contaminated with radionuclides. Such waste may arrive at the facility in sacks, drums or containers and may be disposed of directly in the specific disposal structure or first be taken to the area set aside for its treatment, as necessary.

As each VLLW structure is completed, it will be covered with various layers, the last of which will be of topsoil, allowing for integration into the environment. From that time, a 60-year site surveillance and control phase will begin.

The final cap is likely to comprise a multi-layer structure incorporating (from the top downward) a vegetated soil layer, an anti-intrusion barrier, a secondary soil layer, a gravel drainage layer, a clay layer to inhibit water ingress and an underlying soil layer. Layers of gravel and clay are present at the base of the disposal system. After disposal, it is anticipated that the facility will be unsaturated (though perched water may be present on some of the clay layers or above intact concrete slabs) with the potential for water to drain downward to the regional water table. However, it seems likely that much of the precipitation at the site will be lost in evapotranspiration and that the amount of drainage to depth will be limited.

The facility is located on a hillside at an altitude of about 330 m, but the land falls away rapidly to the east decreasing to an altitude of about 250 m within 1 km of the facility. Various channels drain this slope. A Google Earth view showing the wider geographical context is provided in Figure 1.

Figure 1: View of El Cabril looking to the West

BIOSPHERE METHODOLOGICAL DEVELOPMENTS

The concept of developing formal procedures for the identification and description of biosphere systems for use in post-closure performance assessments was first fully articulated in the IAEA-sponsored BIOMASS project [4]. This methodology was developed further, in the context of taking climate-change into account, in the EU-sponsored BIOCLIM project [5]. Thereafter, there were few methodological developments until the subject was taken up again in the BIOPROTA Geosphere-Biosphere Subsystem (GBS) project that commenced in 2012 and was completed in 2014 [6]. It is now being further addressed within the MODARIA project.

RECENT MODELLING DEVELOPMENTS

Over the last few years, CIEMAT has been at the forefront of efforts to develop process-based models of radionuclide transport in soil-plant systems. This work has been very successful and has led to several peer-reviewed publications [7, 8, 9, 10, 11]. The mathematical model that has been developed describes redox-sensitive radionuclide transport in soils and uptake by plants, taking into account seasonal variations in soil hydrology and considering long-term issues. The model adopts a multi-layer, 1D vertical representation of soil (see Figure 2) that defines flow in the unsaturated and saturated zones using a mass-balance approach in which precipitation inputs are balanced against losses by evaporation, transpiration and drainage, with account taken of increased/decreased water storage in the soil. The model also include plant uptake and cropping losses, as well as volatilization both from soil and plants. Radionuclide decay chains can be represented and radionuclides in soil solution are readily available for root uptake. Radionuclides present in plant residues and returned to soil will be mainly in organic form and are modeled as being released from that organic material by mineralization processes.

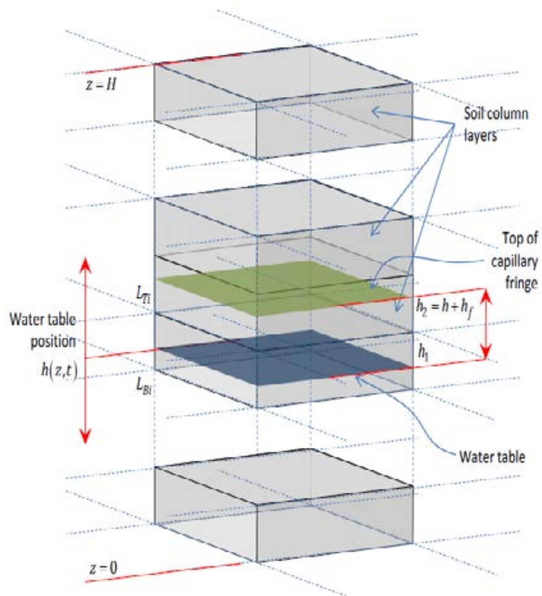

Figure 2. CIEMAT near-surface flow and transport modeling.

A particular interest in biosphere safety assessment is how environmental changes affect the processes and parameters that characterize the most important features of the soil-plant system [12]. This is considered to be important because the food chain is often the dominant exposure pathway for the radionuclides of most significance in post-closure safety assessments. In previously published work, we have shown how to consider the radiological implications of seasonal patterns of temperature, precipitation and water use under different Spanish climatic conditions and investigated the influence of irrigation of both crops for human consumption and feed for animals.

Initial studies with the model for Spanish situation and demonstrate that, it is a powerful tool for exploring the behavior of redox-sensitive radionuclides (e.g. Se-79 and U-238 series) in soil-plant systems under different hydrological regimes. These models are suitable for representing both the upward [8] and downward [9] migration of radionuclides in the soil column, uptake by plants, recycling through soil organic matter and volatilization. In particular, it permits studies of the degree to which secular equilibrium assumptions are appropriate when modeling the U-238 decay chain. Further studies are currently being undertaken examining sensitivities of model results to input parameter values and also applying the model to sites contaminated with U-238 series radionuclides.

CONCLUSIONS AND RECOMMENDATIONS

It proved straightforward to generalize the model developed previously for Se-79 so that it could be applied to the U-238 decay chain [8]. However, simulations are currently restricted to 1D in the vertical. There is a need to extend the models to 2D, so that hill slope analyses, including the effects of both surface and sub-surface water flows, can be conducted. This is particularly relevant for El Cabril, where downslope migration of radionuclides in groundwater and surface waters may occur. There is also a need to consider how either the existing 1D models or extended 2D hill slope models can make use of groundwater and surface water flow fields derived from the 3D modeling of surface-water catchments.

Also, the hillside location of El Cabril raises the issue of whether gully erosion could develop. Indeed, there seems to be some evidence of gullying in the region at the present day. Thus, a model exploring the potential for both generalized erosion by surface wash and gullying erosion under a range of climatic conditions would seem to be required. In particular, the focus could be on arid periods with desertification and limited vegetation cover in which extreme storm events could give rise to a large degree of localized erosion on short timescales.

Although some testing of the existing 1D soil-plant models has been undertaken, more work is needed to firmly establish the validity and usefulness of these models. Thus, the identification of observational data sets for model testing, interpretation of those data and their application in testing the models should be a priority. The existing 1D soil-plant models should be subject to validation by testing them against observational data obtained in both laboratory and field conditions. Also, the 1D model that has been developed could usefully be extended to include other radionuclides of potential radiological significance in VLLW and LILW. These include redox-sensitive radionuclides such as Tc-99. Observations have shown that the kinetics of sorption and desorption of such radionuclides are not instantaneous [13]. However, it is not clear whether moving from a distribution-coefficient based soil-plant model to a kinetically based model would make a great deal of difference to the results obtained from assessment calculations. This could be investigated through a set of scoping calculations in which the existing models were altered to include a kinetic representation of sorption and desorption.

Another subject of particular interest in biosphere safety assessment is how environmental changes affect the processes and parameters that characterize the most important features of the soil-plant system. This is considered to be important because the food chain is often the dominant exposure pathway for the radionuclides of most significance in post-closure safety assessments.

Also, is essential to demonstrate that justified safety assessments can be made for hypothetical future situations, taking into account the biogeochemical recycling of contaminants on very long timescales. Use of models more directly based on underlying processes also has implications for experiments which are likely to become more complex, as additional supplementary information will be required to characterize those processes and field studies (where multi-element analyses of samples will be important in determining the behavior of contaminants and nutrients in relation to each other).

An important issue for El Cabril and for Spanish sites in general is the projection of future climatic conditions. A significant amount of work on this topic was undertaken as part of the BIOCLIM project and reported [5]. However, approaches to climate modeling and to downscaling of climate model results have been substantially enhanced since then. These enhanced approaches are being explored in MODARIA Working Group 6. There is a need for continued involvement in this Working Group, to ensure that the climate modeling undertaken and the downscaling approaches adopted can be applied to generate projections of future climate for Spain as a whole and for the El Cabril site in particular. Specifically, there is a need to develop appropriate techniques for characterizing potential future arid and pluvial episodes.

Since BIOCLIM, considerable work has been undertaken on biosphere system identification, characterization and modeling in the context of specific national programs. The BIOPROTA GBS project was directed to the geosphere-biosphere subsystem. However, the methodology is readily extended to encompass the biosphere as a whole, particularly in an arid, inland environment such as at El Cabril, where major surface water bodies and coastal processes do not have to be considered. Furthermore, with its emphasis on 3D conceptual and mathematical modeling, the methodology is well-suited to developing a conceptual model for a near-surface, engineered facility located within the GBS. However, this extension of the methodology is not being undertaken within the BIOPROTA project, so it will be necessary to undertake it within a Spanish context with a view to applying it to El Cabril.

Additionally, C-14 is often an important contributor to radiological impacts from VLLW and LILW. There have been extensive developments to models representing the behavior of C-14 in soil-plant systems over the last few years [14]. There is a need to review the models that have been developed and adapt them to Spanish conditions, particularly those existing or projected to occur in the future at El Cabril. In particular, the behavior of methane and carbon dioxide in soils under semi-arid conditions and the passage of carbon dioxide through a sparse vegetation canopy will require specific consideration. The relevant timescale is thought to be up to about 10,000 years, determined by the rapidity with which gas and groundwater transport pathways might be developed and the radioactive half-life of C-14. The latest models for the behavior of C-14 in soils and plants will need to be reviewed and adapted to environmental conditions that may occur in Spain over about the next 10,000 years, with a particular emphasis on conditions that may occur at El Cabril.

In terms of impacts on non-human biota, the ERICA Tool is the currently preferred software package used for assessment purposes. Again, consideration needs to be given to the applicability of the ERICA Tool under Spanish conditions, giving particular attention to the radionuclides of key importance in VLLW and LILW disposal. The applicability of the ERICA Tool to conditions in Spain, and particularly those conditions that exist, or may exist in the future, at El Cabril are being evaluated [15], and modifications or updates to the underlying dosimetric and transfer factor databases will be made, as appropriate.

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