Radioactive and Hazardous Waste Management Applications using GoldSim

White Paper

Abstract

GoldSim is a powerful and flexible Windows-based computer program for carrying out probabilistic simulations of complex systems to support management and decision-making in engineering, science and business. The program is highly graphical, highly extensible, able to directly represent uncertainty, and allows you to create compelling presentations of your model. Although GoldSim can be used to solve a wide variety of complex problems, it is particularly well-suited (and was originally developed) to support evaluation of existing and proposed radioactive waste management facilities. Powerful contaminant transport features allow nearly any kind of natural or man-made environmental system to be simulated. This paper provides a brief overview of GoldSim, with special emphasis on radioactive waste management applications.

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Introduction

The Environmental Modeling Problem. Three problems are common to most complex environmental modeling efforts:

- **Uncertainty:** For most real-world applications, a large degree of uncertainty usually exists with regard to the controlling parameters and processes. When carrying out predictive simulations, these uncertainties cannot be properly represented using deterministic techniques alone.
- **Multi-disciplinary:** Most modeling efforts are multi-disciplinary in nature. Unfortunately, in such efforts it is easy for individuals building sub-models to get caught up in the details of their model, and lose sight of the "big picture" (i.e., the ultimate problem which the model is trying to address). The end result is typically separate sub-models which are unjustifiably complex. More importantly, the complex interactions and interdependencies between subsystems are often ignored or poorly represented.
- **Communications:** Many complex environmental models are built such that they can only be understood and explained by the people who developed them. A model which cannot be easily understood (by decision-makers or the public) is a model that will not be used.

The Solution: A "Total System" Probabilistic Approach. Although these problems occur in nearly any kind of complex environmental modeling effort, they are particularly relevant to modeling the performance of proposed and existing radioactive waste management facilities (due to the very long time frames involved, the large uncertainties, and the public's reaction to radioactive waste issues). Therefore, at the request of the US Department of Energy, starting in 1990, we began to develop a new simulation tool to specifically address these problems.

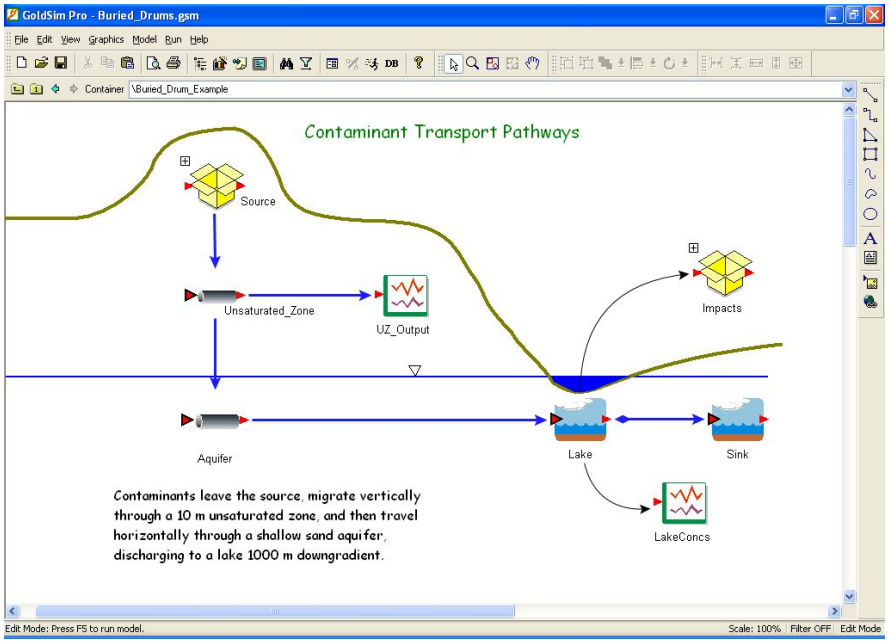
The result of this development effort is a Windows-based graphical simulation tool called GoldSim. GoldSim is a flexible and powerful program for simulating the release, fate and transport of contaminants within complex engineered or man-made environmental systems. It was specifically designed to:

- Explicitly represent uncertainty in processes, parameters, and events;
- Facilitate a "top-down" total system modeling approach aimed at integrating all aspects of the system and keeping a modeling effort focused on the "big picture"; and
- Facilitate the documentation and presentation of complex models to multiple audiences at an appropriate level.

Overview of the GoldSim Simulation Framework

GoldSim is a powerful and flexible platform for visualizing and numerically simulating nearly any kind of physical, financial or organizational system. In a sense, GoldSim is like a "visual spreadsheet" that allows you to visually create and manipulate data and equations (see Figure 1). Unlike spreadsheets, however, GoldSim allows you to readily evaluate how systems evolve over time, and predict their future behavior.

Figure 1: GoldSim offers a highly visual interface.



Because simulation can be such a powerful tool for understanding and managing complex systems, a variety of simulation tools currently exist. The following combination of features, however, makes the GoldSim approach unique:

- ***GoldSim is user-friendly and highly graphical,*** such that you can literally draw (and subsequently present) a picture (an influence diagram) of your system in an intuitive way without having to learn any arcane symbols or notation.
- ***GoldSim is extremely flexible, allowing it to be applied to nearly any kind of system.*** The software allows you to build a model of your system in a hierarchical, modular manner, such that the model can readily evolve as more knowledge regarding the system is obtained. Hence, a GoldSim model can be very simple or extremely complex.
- ***Uncertainty in processes, parameters and future events can be explicitly represented.*** Uncertainty in processes and parameters can be represented by specifying model inputs as probability distributions. The impact of uncertain events (e.g., earthquakes,

floods, sabotage) can also be directly represented by specifying the occurrence rates and consequences of such "disruptive events".

- ***GoldSim is highly extensible.*** You can dynamically link external programs or spreadsheets directly into your GoldSim model. In addition, GoldSim was specifically designed to support the addition of customized modules (program extensions) to address specialized applications.
- ***GoldSim allows you to create compelling presentations of your model.*** A model which cannot be easily explained is a model that will not be used or believed. GoldSim was specifically designed to allow you to effectively document, explain and present your model. You can add graphics, explanatory text, notes and hyperlinks to your model, and organize it in a hierarchical manner such that it can be presented at an appropriate level of detail to multiple target audiences.

A Powerful Flexible Simulator. At the most fundamental level, GoldSim can be used as a powerful, flexible simulator. That is, you may only wish to apply it to a very specific problem addressing one aspect of a complex system (e.g., behavior of an engineered barrier, a site-wide water balance, or movement of contaminants through groundwater or another pathway).

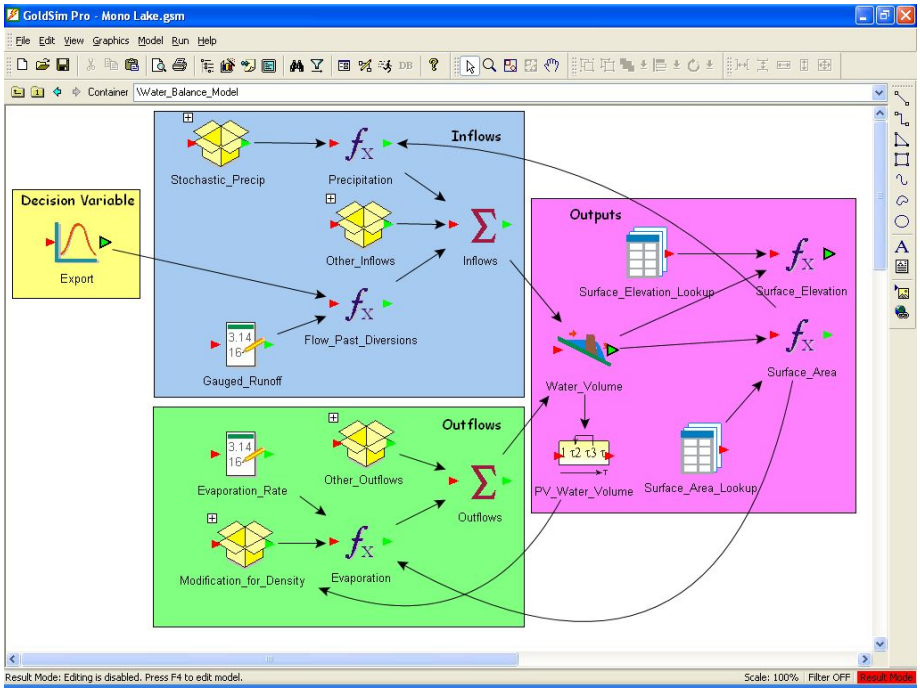


Figure 2: The GoldSim simulation environment is highly-graphical and completely *object-oriented*. That is, you create, document, and present models by creating and manipulating graphical objects (referred to as *elements*) representing data and relationships between the data.

In a sense, GoldSim is like a "visual spreadsheet" allowing you to *visually* create and manipulate data and equations. As can be seen in the simple example shown in Figure 2, based on how the various objects in your model

are related, GoldSim automatically indicates their influences and interdependencies by visually connecting them in an appropriate manner. GoldSim provides a wide variety of built-in objects from which you can construct your models, and, if desired, you can program your own custom objects, and link them seamlessly into the GoldSim framework.

GoldSim's graphical interface and powerful computational features facilitate a wide range of simulations, ranging from a simple screening analysis put together in less than an hour, to a complex application built over a period of several months.

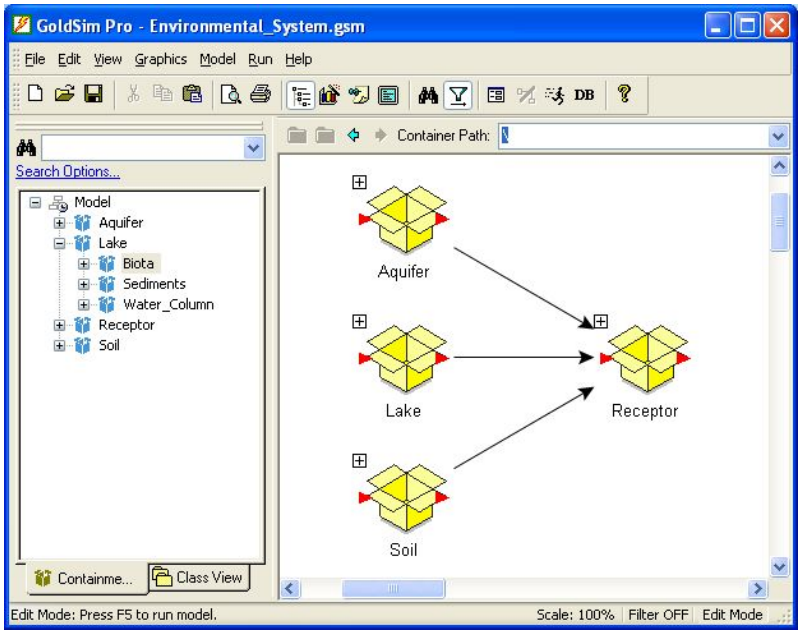
A System Integration Tool. Most radioactive waste management problems are multi-disciplinary in nature. That is, the system being simulated actually consists of many subsystems, and the sub-models for each subsystem must typically be built by people from a wide variety of disciplines. For example, a model intended to evaluate remediation options for a contaminated site likely would include sub-models that are developed by geologists, hydrogeologists, materials engineers, ecologists, health physicists, economists, and perhaps political scientists.

Unfortunately, in many such cases, the model builders get caught up in the details of their sub-models, and lose sight of the "big picture". The end result is typically separate sub-models, which are unnecessarily complex. More importantly, the complex interactions and interdependencies between subsystems are often ignored or poorly represented. Such an approach not only wastes resources, but is often too complex to be explained (and hence used) effectively, and too poorly integrated to represent the entire system in a cohesive and realistic way.

What is needed for such complex, multi-disciplinary systems is a tool that can be used to integrate all of the sub-models into a single, total-system model (see Figure 3). A total-system model focuses on creating a consistent framework in which all aspects of the system, as well as the complex interactions and interdependencies between subsystems, can be represented.

Because GoldSim is flexible and powerful enough to represent practically any aspect of your system, and because GoldSim provides unique capabilities for building your model in a hierarchical, modular manner, it is ideally suited to act as a system integrator. In fact, this was the original and primary use for which GoldSim was designed.

Figure 3: Total-system model including submodels for the aquifer, lake, soil, and receptor systems.



A Visual Information Management System. Even if you can directly and visually access the input data for your model, in order for your simulation model to be useful, you must also be able to explain its assumptions (and the implications of the simulation results) in a compelling and effective manner. GoldSim provides the tools to enable you to do so.

Hence, at the highest and most powerful level, GoldSim can be used as a visual information management system, providing you with the ability to directly link to data sources, as well as describe, document and explain your model in a compelling and effective manner to any audience (see Figures 4 and 5).

Figure 4: Near surface radioactive waste disposal system.

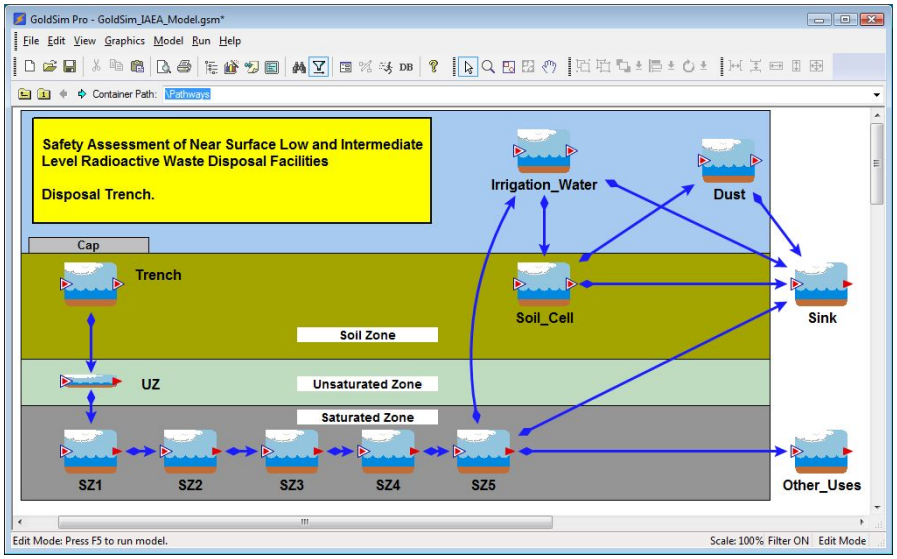
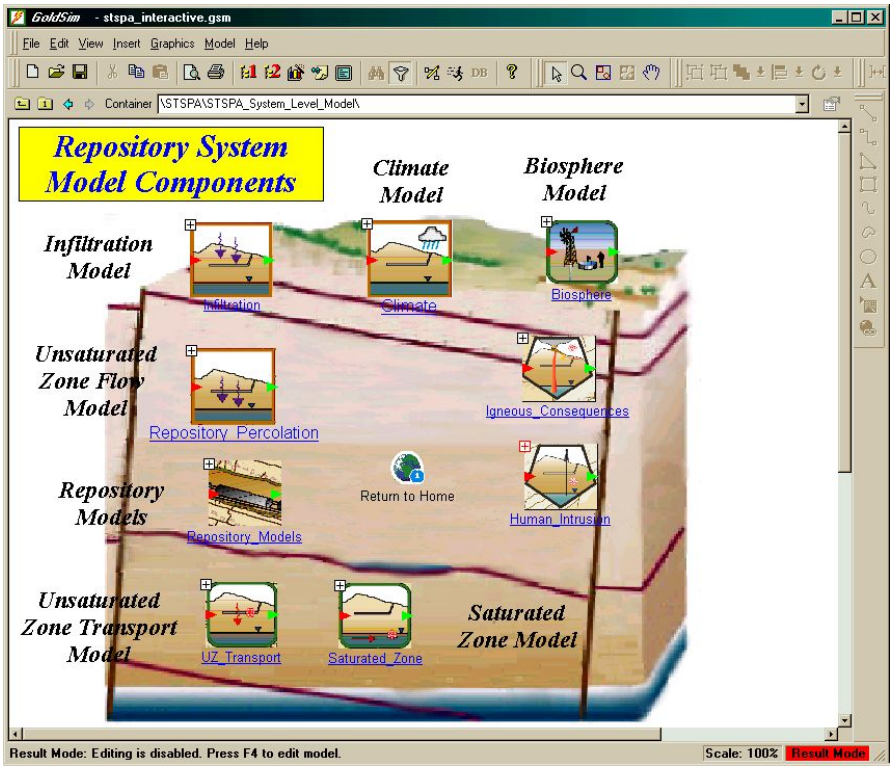


Figure 5: Yucca Mountain radioactive waste repository system.



The GoldSim Contaminant Transport Module

Although the standard elements incorporated within GoldSim can be used to build powerful and complex models, it was realized from the outset of the development of GoldSim that in some situations, specialized elements may be required in order to model some kinds of systems. As a result, GoldSim was designed to facilitate the incorporation of additional modules (program extensions) to enable the program to address specialized problems.

For radioactive waste management applications, the most important of these is the Contaminant Transport (CT) Module. The CT Module is a program extension to the GoldSim simulation framework which allows you to dynamically model mass transport within complex engineered and/or natural environmental systems.

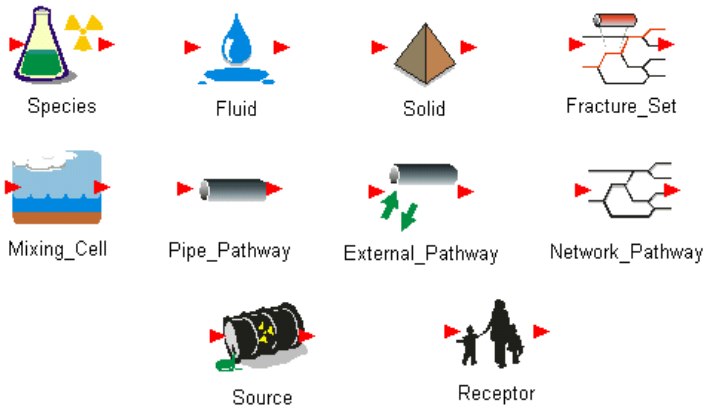
The fundamental output produced by the CT Module consists of predicted mass fluxes at specified locations within the system, and predicted concentrations within environmental media (e.g., groundwater, soil, air) throughout the system. If desired, concentrations in environmental media can be converted to receptor doses and/or health risks by assigning appropriate conversion factors.

Processes Simulated by the CT Module. The CT Module allows the user to explicitly represent the following processes:

- ***Release of mass*** (e.g., contaminants) from specified sources, taking into account both the failure of containers (e.g., drums) in which the contaminants are disposed; and the degradation of any materials in which the contaminants are bound (e.g., grout, metal, glass).
- ***Transport of contaminants*** through multiple transport pathways within an environmental system (e.g., aquifers, streams, atmosphere). The transport pathways can consist of multiple transport and storage media (e.g., groundwater, surface water, air, soil), and both advective and diffusive transport mechanisms can be directly simulated. Transport processes incorporate solubility constraints and partitioning of contaminants between the media present in the system, and can include the effects of complex chemical reactions and decay processes. Transport processes occurring within fractured rock (e.g., matrix diffusion) can also be simulated.
- ***Biological transfer of contaminants within or between organisms***. Like physical transport pathways, biological transport pathways can consist of any number of transport and storage media (e.g., blood, tissue), which can be linked by a variety of transport mechanisms.

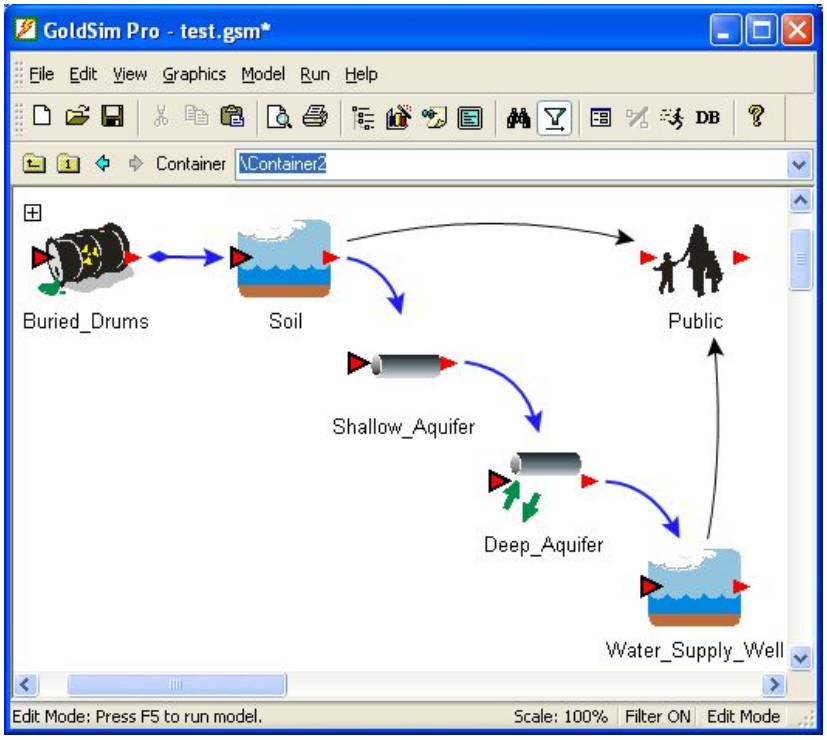
As shown in Figure 6, the CT Module provides this special functionality by adding specialized elements for representing contaminant species, transport media, transport pathways, contaminant sources, and receptors to the GoldSim simulation framework:

Figure 6: Specialized CT Module elements.



By linking these environmental elements together (and integrating them with GoldSim's basic elements), you can build simple or complex contaminant transport simulations (see Figure 7).

Figure 7: CT Module incorporating multiple environmental elements.



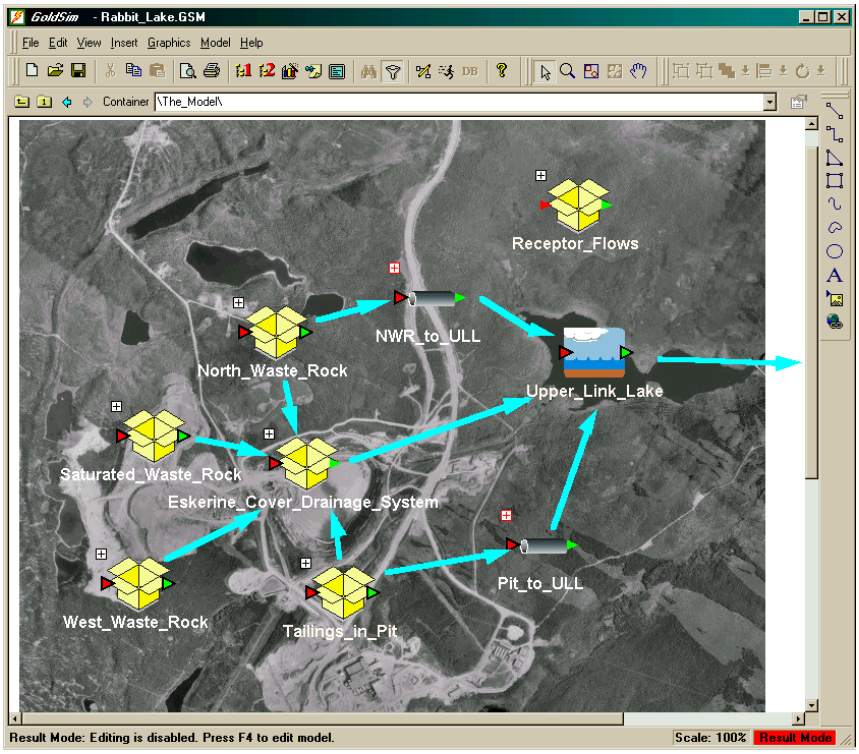
Waste Management Examples

GoldSim (and the CT Module) were originally developed to assist the United States Department of Energy (DOE) in the evaluation of the potential high-level radioactive waste repository at Yucca Mountain, Nevada. It is currently being used to help design remediation measures for contaminated sites and to evaluate the safety of proposed radioactive waste disposal facilities worldwide. A few of these applications are listed below:

- ***Evaluation of Potential Yucca Mountain Repository, Nevada***. The U.S. Department of Energy has been using GoldSim (and an earlier version of the software called RIP) to evaluate the safety of the proposed repository for the nation's spent nuclear fuel at Yucca Mountain, Nevada since 1992.
- ***Spanish Radioactive Waste Disposal Research***. ENRESA, the Spanish radioactive waste management agency, has been using GoldSim (and RIP) since 1992 to evaluate potential host rocks as part of a program to select a disposal site for the nation's spent nuclear fuel.
- ***Evaluation of Waste Disposal Sites, Los Alamos, New Mexico.*** Los Alamos National Laboratory is using GoldSim to aid in characterizing risks and to help identify monitoring requirements for low-level radioactive waste disposal areas.

- ***Remediation and Closure of Uranium Mill Tailings and Mine Workings.*** GoldSim has been used in Germany and Canada (Figure 8) to evaluate alternative remediation and closure options for abandoned mine workings and tailings facilities associated with former uranium mining operations.

Figure 8: GoldSim model simulating closure options for a Uranium Mine in Canada.



- ***Evaluation of Waste Disposal Concepts, Japan***. GoldSim is used by Japan Atomic Energy Agency (JAEA), as well as the Japan Nuclear Energy Safety Organization (JNES) to carry our integrated assessments of concepts for disposal of Japanese high level waste and spent fuel.

- ***Evaluation of Low Level Waste and Underground Nuclear Test Sites, Nevada.*** GoldSim was used to evaluate the influence of different conceptual models of the groundwater flow system on estimates of the extent of radionuclide migration from underground nuclear test sites at the Nevada Test Site. I was also used to evaluate the performance of shallow low level waste facilities at the site.

- ***Long-Term Nuclear Fuel Cycle Planning, Korea.*** The Korea Atomic Energy Research Institute (KAERI) used GoldSim to build a long-term total system model of the entire nuclear fuel cycle for Korea. The model considers fuel acquisition, operation of nuclear power plants, production of spent nuclear fuel, different storage options, potential off-shore reprocessing, innovative domestic and international recycling, and final disposal of wastes.

About the GoldSim Technology Group

The GoldSim Technology Group is dedicated to delivering software and services to help people understand complex systems and make better decisions.

The list of countries and organizations that use GoldSim to address radioactive waste management issues includes the following:

- **Austria** (IAEA)
- **Czech Republic** (RWRA, NRI)
- **Egypt** (Egyptian Atomic Energy Agency)
- **France** (ANDRA, IRSN)
- **Germany** (DBE Technology, Wismut)
- **Japan** (JAEA, JNFL, JGC, JNES, Kajima, MHI, AIST, Obayashi, NUMO, Taisei)
- **Peoples Republic of China** (China National Nuclear Corporation)
- **Slovak Republic** (VUJE)
- **South Korea** (KAERI, KINS)
- **Spain** (ENRESA)
- **Taiwan** (INER)
- **United Kingdom** (National Nuclear Laboratory, Nuclear Decommissioning Authority, Environment Agency, Serco Assurance, Galson, Quintessa)
- **United States** (Argonne National Laboratory, Hanford ,Los Alamos National Laboratory, Nevada Test Site, Nuclear Regulatory Commission, Sandia National Laboratories, Savannah River National Laboratory, Southwest Research Institute, Yucca Mountain Project,)

The GoldSim software package is a generalized simulator suitable for modeling any type of real-world system and has been used to solve problems related to strategic planning, environmental management, and engineering risk analysis. For additional information, please contact:

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