GENII-LIN: a Multipurpose Health Physics Code Built on GENII-1.485

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ABSTRACT

The aim of the GENII-LIN project was to develop an open source multipurpose health physics code running on Linux platform, for calculating radiation dose and risk from radionuclides released to the environment. The general features of the GENII-LIN system include

[1] capabilities for calculating radiation dose both for acute and chronic releases, with options for annual dose, committed dose and accumulated dose
[2] capabilities for evaluating exposure pathways including direct exposure via water (swimming, boating, fishing), soil (buried and surface sources) and air (semi-infinite cloud and finite cloud model), inhalation pathways and ingestion pathways.

The release scenarios considered are:

- acute release to air, from ground level or elevated sources, or to water;
- chronic release to air, from ground level or elevated sources, or to water;
- initial contamination of soil or surfaces.

Keywords: radiation protection, Linux, health physics, risk analysis, environmental impact.

DESCRIPTION OF THE CODE

The GENII-LIN [1] code package can evaluate doses resulting from two general scenario types: farfield and near-field. A far-field scenario is defined as one that determines the impact of a particular release of radioactive material into a wide environment, such as doses from releases from a stack to individuals or populations downwind. In a near-field scenario, the focus is on the doses an individual could receive at a particular location as a result of initial contamination or external sources, i.e., buried waste or contaminated soil. In a near-field scenario, contamination levels in specific environmental media may be known. A far-field scenario focuses outward from a source, and a near-field scenario focuses in toward a receptor. Of course, the two types are not mutually exclusive. Some doses to individuals from remote sources can be calculated as either farfield or nearfield with the same result. Specific examples of common types of farfield and nearfield scenarios are given below.

Far field scenarios
A number of commonly encountered scenarios may be classed as far-field. The following are types of releases of radioactive materials into the wider environment:

- chronic atmospheric releases - prospective or retrospective doses to individuals or populations at specified distances and directions from the radioactive source, via submersion, inhalation, deposition groundshine, and food pathways. This class of scenario is commonly used for demonstrating compliance to regulations that involve emission sources.
- acute atmospheric release - prospective or retrospective doses to individuals or populations at specified distances and directions from an acute radioactive release; via submersion, inhalation, deposition groundshine, and food pathways. This class of scenario is often used in safety analysis reports or environmental impact statements.
- chronic surface water releases - prospective or retrospective doses to individuals and populations at specified distances downstream of a release point via swimming, boating, shoreline, drinking water, aquatic foods, irrigated terrestrial foods and animal products, soil contaminated via irrigation, and other pathways associated with liquid releases. This class of scenario is also often encountered during the demonstration of compliance with regulations.
- acute surface water releases - prospective or retrospective doses to individuals and populations at specified distances downstream of a release point via swimming, boating, shoreline, drinking water, aquatic foods, irrigated terrestrial foods and animal products, soil contaminated via irrigation, and other pathways associated with acute liquid releases. This class of scenario is also associated with safety analysis reports or environmental impact statements.

Near-Field Scenarios
Many other types of scenarios may be considered to be near-field.

- initial surface contamination - individual doses resulting from contact with contaminated soil or surfaces via direct contact, resuspension, or crop uptake. Calculations of this nature can be used to analyze the impact of spills or remedial actions.
- initial subsurface contamination - individual doses resulting from contact with contaminated soil or surfaces via direct contact resuspension, or crop uptake. The surface soil may be contaminated via manual redistribution of the material or through biotic transport. Calculations of this nature can be used to analyze the impacts of waste management options. Often a time delay may be included to account for radioactive decay of the source.
- ground water contamination - prospective or retrospective doses to individuals and populations from a given water concentration via drinking water, irrigated terrestrial foods and animal products, soil contaminated via irrigation, and other pathways associated with liquid releases. This class of
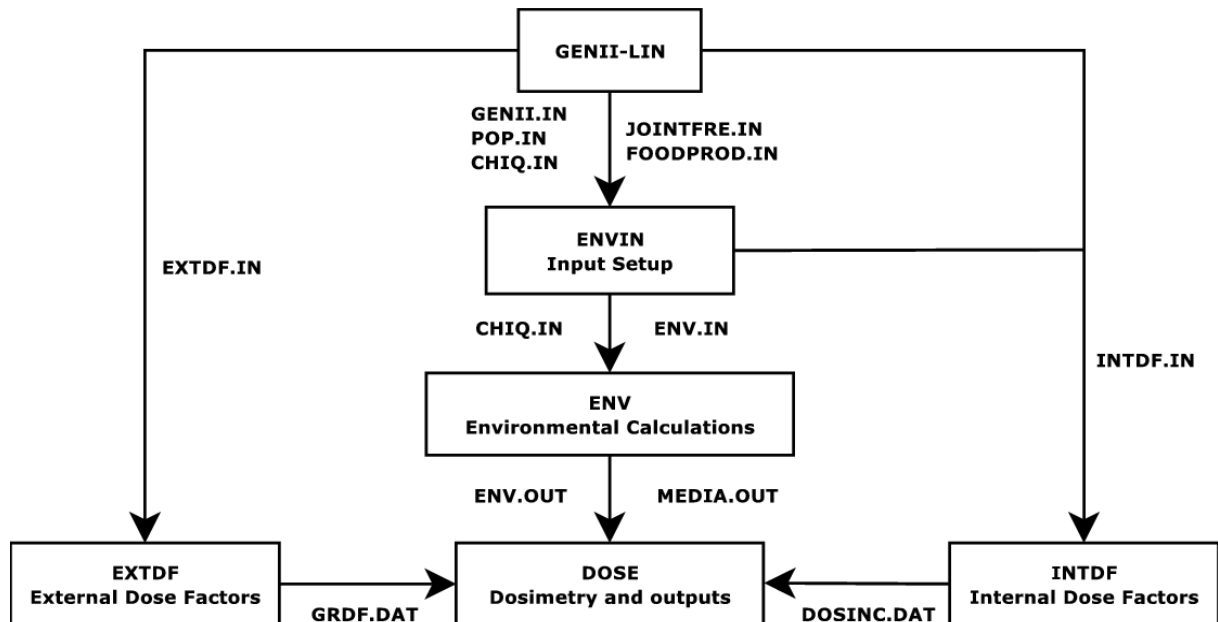
Fig. 1 GENII-LIN structure. Information transferring between computational modules is done through the data communication files. These files are either supplied by the user through the GUI or generated by the computational modules to provide information to subsequent modules.

scenario is also often used in demonstrating compliance with regulations.

- cumulative effects - prospective calculations combining initial soil contamination with additional contributions from an external atmospheric or liquid source. This type of calculation is representative of how near-field and far-field calculations can conceptually be combined.

We remark that the near-field and far-field scenarios are not necessarily mutually exclusive, and in some instances either approach may be used in defining them.

Exposure pathways
The "exposure pathways" are the potential routes through which people may be exposed to radionuclides or radiation. The general pathways are external exposure, inhalation and ingestion.
The pathways are defined depending on the ways people could be exposed for a given circumstance. In this vein, an appropriate collection of defined pathways can also be considered as the definition of an "exposure scenario". A conceptualization of the types of exposure must be made before the pathways can be fully defined, reason why "scenarios" are usually defined before the parameters are selected for the "pathways."

CODE FUNCTIONAL DESCRIPTION

GENII-LIN is the result of implementing the GENII software package [2-5] on the Linux platform. The GENII portion of the GENII-LIN package contains the program which was developed to incorporate the internal dosimetry models recommended by the International Commission on Radiological Protection (ICRP) into the environmental pathway analysis models used at Hanford. GENII, which is available from RSICC as CCC-601, is a coupled system of six programs (env, envin, dose, intdf, extdf, ditty) and the associated data libraries that comprise the Hanford Dosimetry System (Generation II) to estimate potential

radiation doses to individuals or populations from both routine and accidental releases of radionuclides to air or water and residual contamination from spills or decontamination operations. We chose to build our code on GENII, because it is well documented, technically peer-reviewed, opensource and is still considered by regulatory authorities as a reference tool.
The structure of the GENII-LIN software package is schematically reported in Fig. 1.

ENVIN
The ENVIN module of the GENII package controls the reading of the input files and organizes the input for optimal use in the environmental transport and exposure module, ENV. The ENVIN code acquires the basic input, reads the basic data libraries and other optional input files, and generates a data transfer file organized into sequential segments based on radionuclide decay chains. Input to ENVIN occurs by means of a standardized file containing scenario, control, and inventory parameters. Radionuclide inventories can be entered as release to air or water, concentration in basic environmental media (air, soil, or water), or concentration in foods. When certain atmospheric dispersion options have been selected, this module can generate tables of atmospheric dispersion parameters (χ/Q) that will be used in later calculations. If the finite plume air submersion option is requested, in addition to the atmospheric dispersion calculations, preliminary energy-dependent finite plume dose factors are also prepared. ENVIN prepares the data transfer files that feed as input the ENV module. It also puts out the first portion of the calculation documentation: the input parameters report.

ENV
The ENV module is the portion of the GENII package that calculates the environmental transfer, uptake, and human exposure to radionuclides that result from the chosen scenario for the defined source term. The code reads the input files from ENVIN, and then for each radionuclide chain sequentially performs calculations to establish the conditions at the start of the exposure scenario. Environmental concentrations of
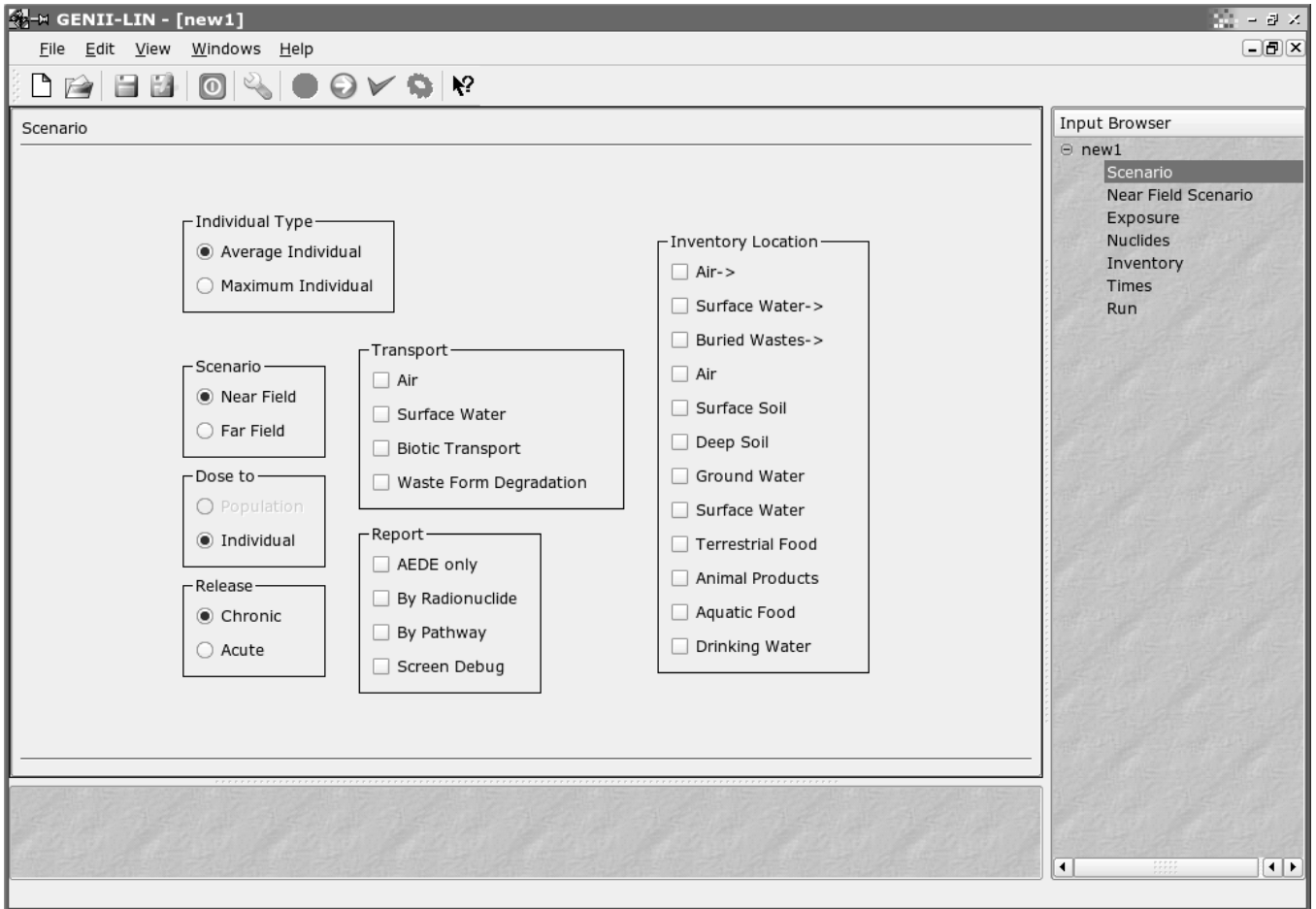
Fig. 2 The GENII-LIN system includes a central control unit written in C++, with a graphical user interface, built on the Qt libraries by Trolltech. Wizard-like editors allow the user to effectively address the parameters required for scenario generation and data input, internal and external dose factor generators, and environmental dosimetry programs.

radionuclides are established at the beginning of the scenario by assuming decay of preexisting sources, considering biotic transport of existing subsurface contamination, and defining soil contamination from continuing atmospheric or irrigation depositions. Then, for each year of postulated exposure, the code estimates air; surface soil, deep soil, and ground and surface water concentrations of each radionuclide in the chain. Human exposures and intakes of each radionuclide are calculated for the pathways of

- external exposure from finite or infinite atmospheric plumes;
- inhalation;
- external exposure from contaminated soil, sediments, and water;
- external exposure from special geometries;
- internal exposures from consumption of terrestrial foods, aquatic foods, drinking water, animal products, and inadvertent intake of soil.

The intermediate information on intake rates and annual media concentrations are written to data transfer files. While these may be accessed directly, they are usually used as the input to the DOSE module of GENII.

DOSE

The DOSE module of the GENII package reads the annual intake and exposure rates defined by the ENV module and converts them to radiation dose.

The calculation of external dose is done with precalculated

factors from the EXTDF module, and the calculation of internal dose is done with precalculated factors from the INTDF module.

The types of doses calculated in the DOSE module include:

- One-Year Dose: the population or individual dose that results from one year of exposure (external plus internal). This is the dose currently used for comparison with occupational exposure standards and the one originally used for comparison with public standards.
- Committed Dose: the population or individual dose that results from one year of external and internal exposure plus the extended internal dose that results from the one-year intake (ingestion plus inhalation). Normally, a 50 or 70 year dose-commitment period is used (i.e., the one-year intake period plus 49 or 69 years). This dose is the one currently being used by most of those who calculate public doses. The committed dose is used as a measure of the potential, longterm impact of accidents and routine releases: the residual radioactive material left in the body continues to produce a dose after the initial one-year period ends. The integral of the dose rate over 50 or 70 years gives the committed dose that results from one year of intake.
- Cumulative dose: the population or individual lifetime dose from external exposure plus intake via ingestion and inhalation. This includes the dose from radionuclides that accumulate (and physically decay) in the environment during the exposure period. The cumulative dose is used to assess the total potential impacts from operations that have
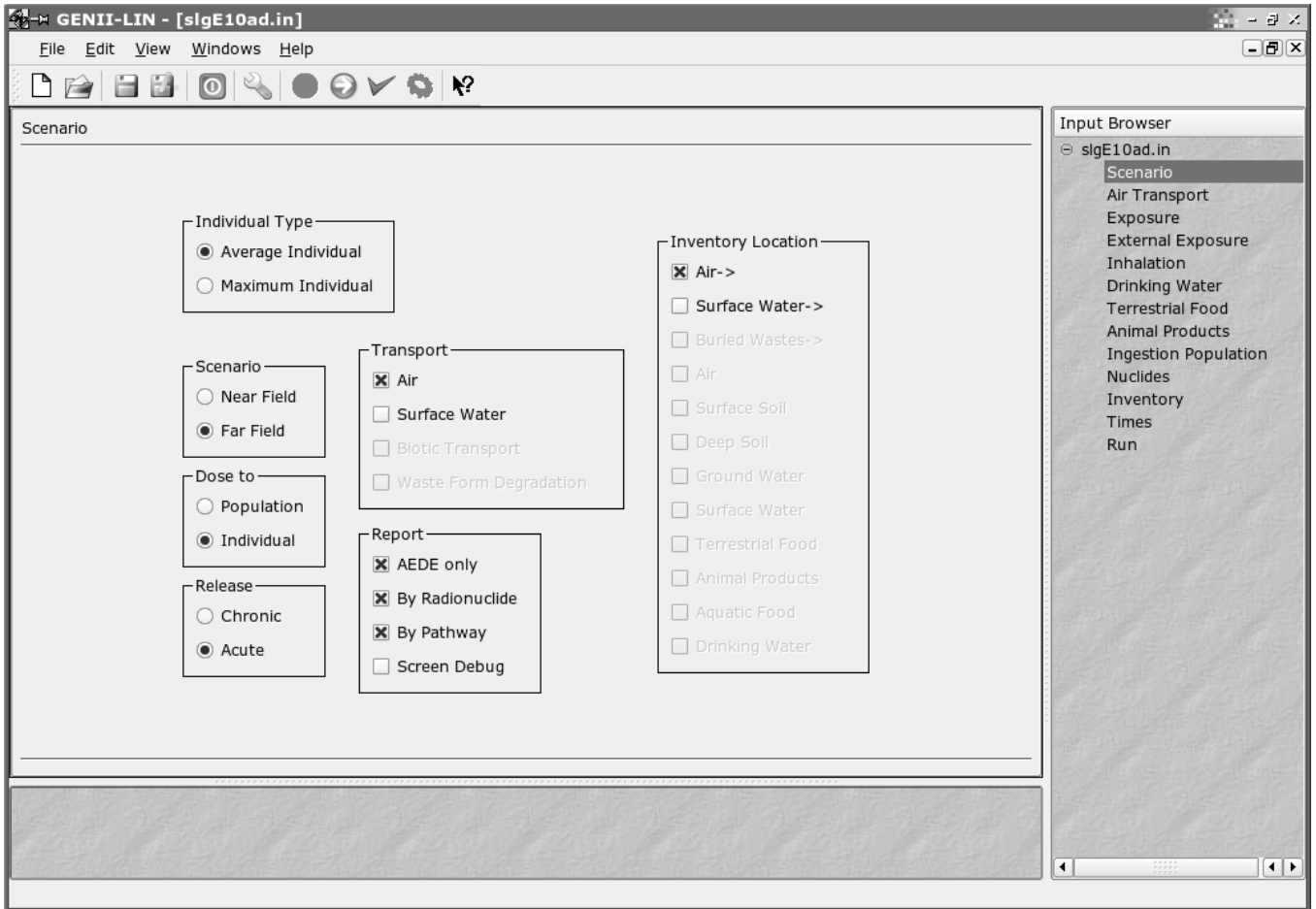
Fig. 3 As may be required for each of the selected options, GENII-LIN activates other pages to control input of parameters for user selected scenarios.

chronic releases over a period of several years or from significant deposition resulting from accidents.

- Maximum Annual Dose - the largest annual dose that could occur during a specific period (e.g., 50 or 70 years). This calculation accounts for each year's external exposure plus the internal dose from radionuclides taken in during the year of interest and all previous years. The maximum annual dose is identified by including all organ doses. This type of dose estimate corresponds most closely to the existing annual dose limits for occupational and public exposure. The maximum annual dose is calculated for scenarios that consider human intrusion or long-term casual exposure to disposed wastes, for environmental impact statements, and for the allowable residual contamination level evaluations used for decommissioning operations. The maximum annual dose is calculated by assuming an initial concentration of radionuclides in soil, concrete, piping, and other materials. These concentrations are reduced over time by physical decay. The annual dose rate to the exposed individual from internally deposited radionuclides increases until the body burden reaches equilibrium with the environmental levels of the physically decaying radionuclides. The year that equilibrium occurs usually corresponds to the maximum dose rate. The maximum-dose-rate year may not occur until many years after-the initial exposure.

DOSE also prepares the remainder of the normal output report of doses, optional doses by pathway and by radionuclide. This output is combined with that from the ENVIN routine to comprise the total routine reports.

EXTDF

The EXTDF module allows easy and uniform calculation of external dose-rate factors for

- submersion in an infinite cloud of radioactive materials;
- immersion in contaminated water;
- direct exposure to plane or slab sources of contamination.

EXTDF also allows for the creation of special dose-rate factors for sources of other geometries in the GENII system. The EXTDF code is a modification and enhancement of the well-known shielding code ISOSHLD (Engel, Greenborg, and Hendrickson 1966). The portion of ISOSHLD that can be used to calculate source strength from reactor fission fuel (the RIBD routines) has been eliminated. The data libraries of radionuclide decay information and gamma and beta yields have been updated from the DRALIST compilation of Kocher [6]. The ISOSHLD code uses a point kernel integration technique; i.e., the dose at the exposure point is the contribution from a large number of individual point sources. A numerical integration is performed over the source volume to obtain the total dose. For a limited number of geometries, an analytical solution is used. The geometries available in the EXTDF are the standard 14 available in ISOSHLD.

EXTDF can only calculate normalized dose rate factors. It can not be used for routine shielding calculations because it automatically reads and computes factors for unit inventories of all radionuclides in the GENII master nuclide library.
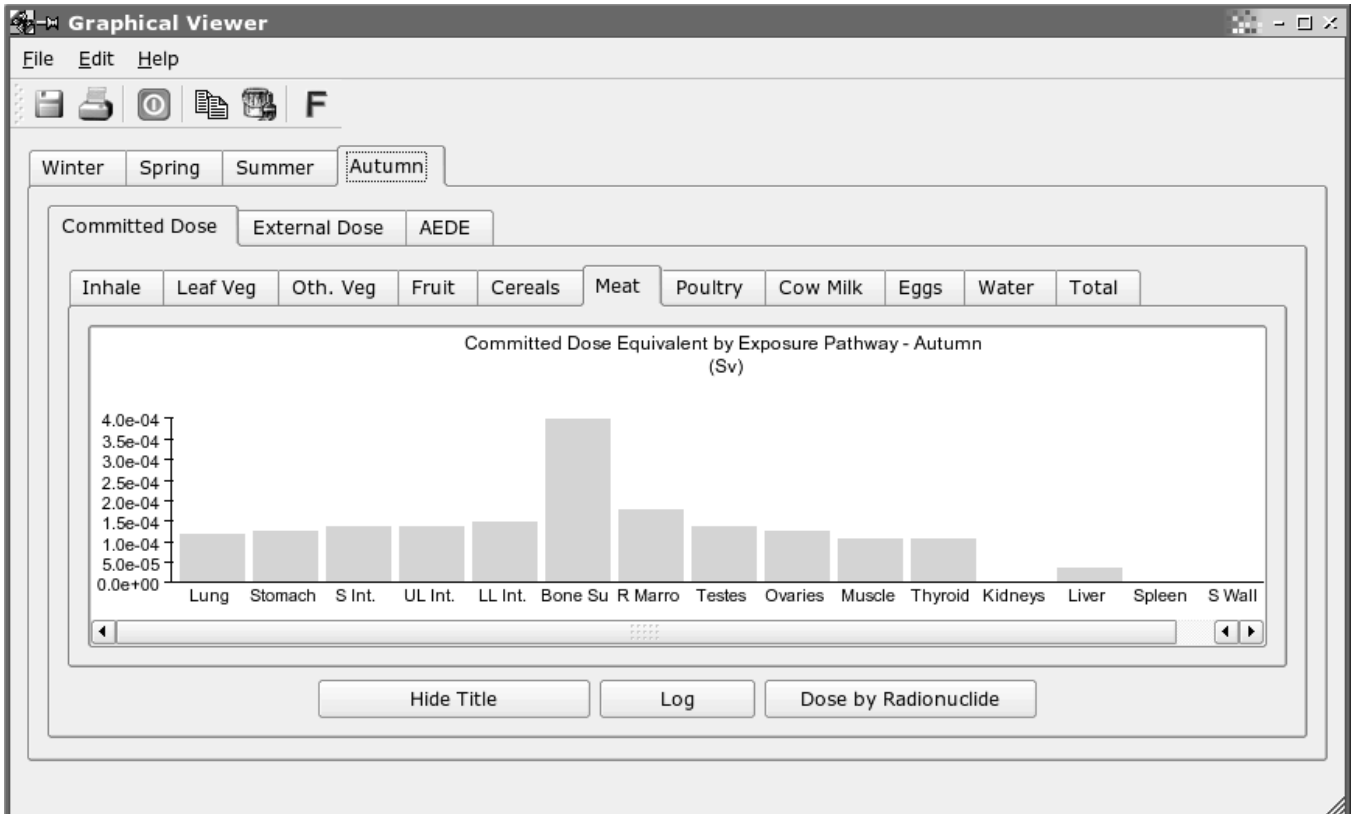
Fig. 4 A full featured viewer allows a graphical display of the results. Under certain circumstances (acute air release is considered here) the output may be very detailed and complex.

INTDF

The INTDF code, does not itself provide effective dose equivalent (whole body dose). Instead, it calculates the incremental organ doses for each year following an initial intake. INTDF estimates the dose equivalents in a number of target organs from the activity in a given source organ based on ICRP-30 models and biokinetic values for radionuclide residency and transport in the body. For each type of radiation, the dose equivalent in a target organ is the product of two factors:

- the total number of nuclear transformations of the radionuclides in the source organ over the period of interest following intake
- the energy absorbed per gram in the target organ, suitably modified for the quality factor, from each radiation type per transformation of the radionuclides in the source organ.

This initial value problem is solved using a coupled set of differential equations. The output is the incremental dose to each organ, which is then used by DOSE to assemble annual doses, dose commitments, and accumulated doses.

THE CENTRAL CONTROL UNIT

The GENII-LIN system includes a central control unit written in C++, with a graphical user interface (Fig.s 2, 3), built on the Qt libraries by Trolltech [7]. By activating wizard-like editors the user can effectively address the parameters required for scenario generation and data input, internal and external dose factor generators, and environmental dosimetry programs.

A series of well-ordered screens steps the user through the process of problem definition and selection of options for setting up the files for input to the environmental dosimetry programs and dose factor generators. As may be required for each of the selected options, GENII-LIN activates other pages to control input of parameters for user selected scenarios (Fig. 3). The wizard requests only pertinent inputs, makes default values available for all parameters, suggests reasonable parameter value ranges, and performs error checking for scenario compatibilities.

After starting calculations, a signal and data exchange is established between the central unit and the five subsequent modules, that allows a real time control of the operations.

Information transferring between computational modules is done through the data communication files reported in Figure 1. These files are either supplied by the user through the GUI or generated by the computational modules to provide information to subsequent modules. The content and format of these files is defined by the requirements of the GENII-LIN software package. The computational modules must read and write information consistent with these requirements. The user can modify the content of the files with a text editor, however the format is mandatory.

GENII-LIN comes with both text and graphical full featured file viewers for output management (Fig.s 4, 5).
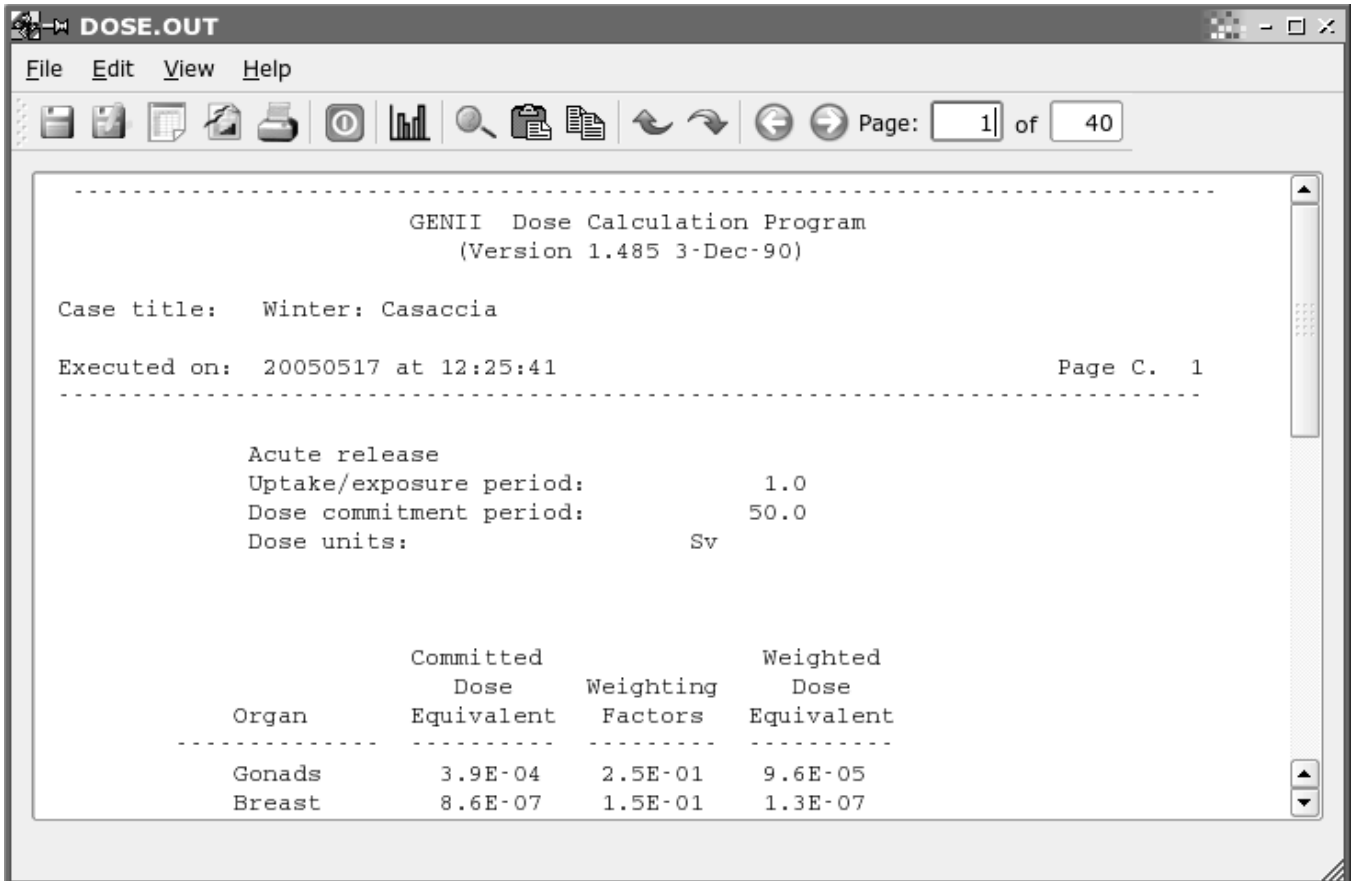
Fig. 5 An embedded text viewer let the user browse the multi page ascii output of the code. Data can be exported both to csv files and Open Office spreadsheets (see the tool buttons).

Output data can be extracted and exported to CSV files for ease importing into spreadsheets. Also a tool for direct exporting to Open Office spreadsheets is available.

The plots produced are fully customizable, by changing fonts and colors, and can be printed, copied to clipboard or saved with several formats (bmp, jpeg, tiff, eps...).

GENII-LIN is modular and strictly 'object oriented'. The computational modules are managed by the control unit but are not embedded. With little effort, it is possible to modify the existing modules and to introduce new ones. Each page of the wizard is a class, which can be easily re-implemented without affecting the other ones.

The upcoming new major release (GENII-LIN 2.0), will incorporate into the existing environmental pathway analysis models the more recent internal dosimetry models recommended by the ICRP 72 and the radiological risk estimating procedures of FGR 13.

It is also planned to add a two-dimensional finite element code for the analysis of contaminant transport in groundwater [8,9], and tools to give a stochastic interpretation of the simulation results (uncertainty analysis) [10], through the assignment of a probability distribution function to the more significant transport and source parameters.

SYSTEM REQUIREMENTS

GENII-LIN requires an IBM or equivalent PC with Linux operating system. A FORTRAN 77 compiler is needed for building computational modules, a C++ compiler is needed for the GUI. We recommend the GNU compiler collection, release

3.3.3 or later is recommended. Finally GENII-LIN requires the Qt libraries from Throlltech, version 3.3.1 or higher.

CODE AVAILABILITY.

The latest public release of the code is available for download from the NEA Data Bank (CCC-0601/04). Both sources and prebuilt binaries can be retrieved. Also the RSICC data center received a copy of the package.

CONCLUSIONS

The first multipurpose health physics code for Linux has been released by implementing the GENII software package on the Linux platform. GENII-LIN, as the new code has been called, can be used for estimating potential radiation doses to humans as a result of radionuclides in the environment. The code addresses both routine and accidental releases of radionuclides to air or water in addition to other situations (residual contamination from spills or decommissioning operations). Internal radiation dose calculations are performed using the methods recommended by the ICRP as described in ICRP 26 and 30. The upcoming new major release (GENII-LIN 2.0), will incorporate into the existing environmental pathway analysis models the more recent internal dosimetry models recommended by the ICRP 72 and the radiological risk estimating procedures of FGR 13.

GENII-LIN comes with a revised structure and full featured GUI built on the Qt libraries by Trolltech, available under the

term of the GNU public license.

The code has been used for environmental impact and safety analysis for several italian nuclear fuel cycle facilities. It revealed itself to be very stable and reliable.

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