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Generic model for combined Tier-1 assessments for humans and wildlife

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Acronyms and abbreviations

ARN: Autoridad Regulatoria Nuclear.

CROM: Screening Code for the Assessment of the Radiological Impact of Discharges in Humans.

CROMERICA: Computer code implementing an integrated screening model for humans and wildlife (consistent combination of CROM and Tier 2 of the ERICA Assessment Tool).

CIEMAT: Centro de Investigaciones Energéticas, Medio Ambientales y Tecnológicas.

EMCL: Environmental Media Concentration Limit.

ENRESA: Empresa Nacional de Residuos Radiactivos SA.

ERICA: FP6 EURATOM funded project Environmental Risk from Ionising Contaminants: Assessment and Management.

ERICA Tool: Assessment model resulting from ERICA project.

ETSII-UPM: Escuela Técnica Superior de Ingenieros Industriales-Universidad Politécnica de Madrid.

GUI: Graphical user interface.

IAEA: International Atomic Energy Agency.

MODARIA Modelling and Data for Radiological Impact Assessments.

Pdf: Probability Density Function

QA: Quality Assurance.

RPD-HPA: Radiation Protection Division. Health Protection Agency.

SRS 19: IAEA Safety Reports Series No. 19.

STAR: STrategy for Allied Radioecology.

TXT: Text.

XML: eXtensible Markup Language.

1 Introduction

Despite some conceptual differences (STAR, 2013bis), the assessment models for both humans and wildlife require contamination levels of environmental media such as air, freshwater, soil, etc. as inputs. Currently regulators and other end-users have to use different tools for human and environmental assessment. These tools may not even use the same sub-model to estimate media activity concentrations. The commonality in required inputs was here used in a pragmatic approach to design a first step combined human-environment assessment model.

Based in state-of-the-art models for human exposure assessment the combined model provides the first step of iteratively proceeding towards process-oriented modelling. Starting from a known (either measured or calculated) contamination of environmental media (air, water, soil, etc.), the contamination of non-human species is generally calculated using empirical parameters such as whole-organism concentration ratios (CR) and sediment-water distribution coefficients (K_d).

Assessment models for humans and non-human species both require contamination levels of environmental media. If environmental media contamination levels are not known, a sub-model that calculates the contamination levels of these media from discharge data is a logical step in the development of a combined model. This common sub-model can be taken from existing models for humans or wildlife exposure assessment as both the CROM model (human exposure) and ERICA Tool (environmental assessment) do (Robles et al., 2007; Brown et al., 2008).

The IAEA performs a continuous effort improving simple mathematical models for calculating environmental concentrations arising from radioactive continuous discharges from installations for use by their Member States. In 1982, Safety Series No 57 (IAEA, 1982) was issued as a guidance on models for predicting environmental transfer for assessing doses to the most exposed individuals (critical groups) of humans. That publication was superseded in 2001 by the IAEA Safety Report Series No 19 (SRS19) where some international consensus on the mathematical models to be applied was achieved (IAEA, 2001). In 2011 the revision of the report began and the IAEA is expected to issue a new publication in 2015.

Within the EC-funded project STAR, milestone MS3.3 (STAR, 2013) collated the models needed to integrate human and environmental assessment approaches, mainly based on the IAEA SRS19 report. These models will be revised after the publication of the upcoming IAEA report.

The generic models described in SRS19 have been previously implemented as a computer code, developed by CIEMAT, and named CROM (Robles et al., 2007; CROM, 2011). This was transferred to the IAEA in 2007 for free worldwide distribution. The dispersion models from SRS19 were also implemented in the ERICA Tool computer code for assessing radiation risk to wildlife (Beresford et al., 2007). Coupling both approaches, providing the contamination levels of environmental media in a single code, would accomplish the aims of the STAR project.

A combined assessment tool, CROM8, will be made available on the STAR website (http://www.star-radioecology.org/). This code will improve the situation for regulators and other end-users who will no longer need different tools (which may not even use the same sub-model to estimate media activity concentrations) for human and environmental assessments.

2 Description of the CROM code

CROM is a generic environmental model code developed by CIEMAT in collaboration with the Polytechnic University of Madrid. The code is mainly based on Safety Report Series No 19. It was designed to automate the calculation of radionuclide concentrations in different compartments of the environment and their transfer to the human food chain, as well as estimating the effective dose for humans. The code in its versions 5, 6 and 7 was distributed worldwide by the IAEA. CROM (in all supported versions) is available and freely distributed by contacting the IAEA (d.m.telleria@iaea.org) or downloading it from ftp://ftp.ciemat.es/pub/CROM.

CROM uses generic models for diffusion and dilution, based in IAEA's report SRS 19 (IAEA, 2001), with enough flexibility to be used for more realistic calculations using local parameters. In order to estimate the radionuclide concentrations in the environmental media, the quantities and types of radionuclides to be discharged (the source term), the mode and characteristics of the discharge and the receptor points, up to five, need to be specified.

The atmospheric dispersion model is a Gaussian plume model designed to assess annual averaged radionuclide concentrations in air (this model was validated for distances <80 km (Miller et al., 1987)). It is used for the calculation of the rate of deposition at various points in the region of interest from long-term releases, assuming a 30-years continuous emission and a neutral atmospheric condition. The model accounts for the effects of any buildings in the vicinity of the release and the effect of the roughness of the ground in the wind profile. The basic meteorological variables required for each individual air concentration calculation are the wind direction and the geometric mean of the wind speed at the physical height of the release point. The code allows the use of diffusion factors for different stability categories other than D (neutral), and also the introduction of effective heights but does not calculate them.

The surface water models account for dispersion in rivers, 'small' and 'large' lakes, estuaries and along the coast. These models are based on analytical solutions of advection-diffusion equations describing radionuclide transport in surface water with steady state uniform flow conditions. The contamination of surface water from routine discharges to the atmosphere is also considered for small lakes. All the models contain many default values that can be used in the absence of local specific information. The models can also be easily used for sewerage systems with some considerations.

The terrestrial food chain models accept inputs of radionuclides from both the atmosphere and the hydrosphere and account for the build-up of radionuclides on surface soil over a 30-year period. The process of radioactive decay and build-up is taken into account in the estimation of the retention of radionuclides on the surfaces of vegetation and on soil, and in the assessment of the losses owing to decay that may occur during the time between production and vegetable consumption. The food categories considered are milk, meat and vegetables. The calculations of uptake and retention of radionuclides by aquatic biota uses selected element specific bioaccumulation factors (comparable to concentration ratios used for wildlife) that describe an equilibrium state between the concentration of the radionuclide in biota and water. The types of aquatic food considered are freshwater fish, marine fish and marine shellfish.

The estimated radionuclide concentrations in air, soil, sediment, food and water (calculated after a 30-years period of discharge) are combined with the annual rates of intake, the occupancy factors and the appropriate dose conversion coefficients to obtain the maximum human effective dose in year 30 for the combined external and internal exposure. The dose conversion coefficients for internal exposure are taken from Safety Series No 115 (IAEA, 1996). For external exposure they have been calculated on the basis of the coefficients and equations given in the Federal Guidance Report No 12 (Eckerman et al., 1993). The model takes into account external dose rates from radionuclides due to cloud immersion, soil, sediments and water submersion. The effective doses from external exposure and radionuclide intakes are calculated for six age categories.

Version 7 of CROM (CROM7) implements capabilities for propagating uncertainties, by using Monte Carlo methods. It allows the use of probability density functions for almost all the parameters and variables used in the code. All the results of the Monte Carlo calculations are presented in text files (as vectors) and in graphical mode. CROM 7 implements a default database with data for 152 radionuclides and seven examples of application based on examples included in SRS19. This version was used as a base for integrating both approaches for radiation protection of the humans and the biota in the CROM8.

3 The ERICA Tool

The ERICA Tool (Brown et al. 2008) is freely available software (http://www.erica-tool.com/) which implements the ERICA integrated approach (Beresford et al. 2007) to the assessment of risk to wildlife from ionising radiations. Version 1.2 of the Tool was released in November 2014.

The ERICA Tool is built around a tiered assessment approach with an initial screening tier (Tier 1) requiring minimal user input, through to Tier 3 with probabilistic simulation for uncertainty analyses. The Tool considers three generic ecosystems (Marine, Freshwater and Terrestrial) and include a number of default ‘Reference Organisms’ which are amongst other things supposed to be representative of European protect species, different trophic levels and organisms likely to be highly exposed.

The dispersion models applied in ERICA Tool are also based in IAEA's report SRS19, therefore merging a combined tool where the parameters and assumptions used in this code is possible.

4 CROM8 – towards an integrated assessment

One of the aims of STAR has been to investigate the possible integration of human and non-human radiation protection frameworks. This, together with the advances in the same direction by the IAEA, was taken into account when developing version 8 of the CROM code (CROM8, Figure 1) by CIEMAT and the ETSII-UPM. Development was cosponsored by STAR, the IAEA, CIEMAT and ENRESA.

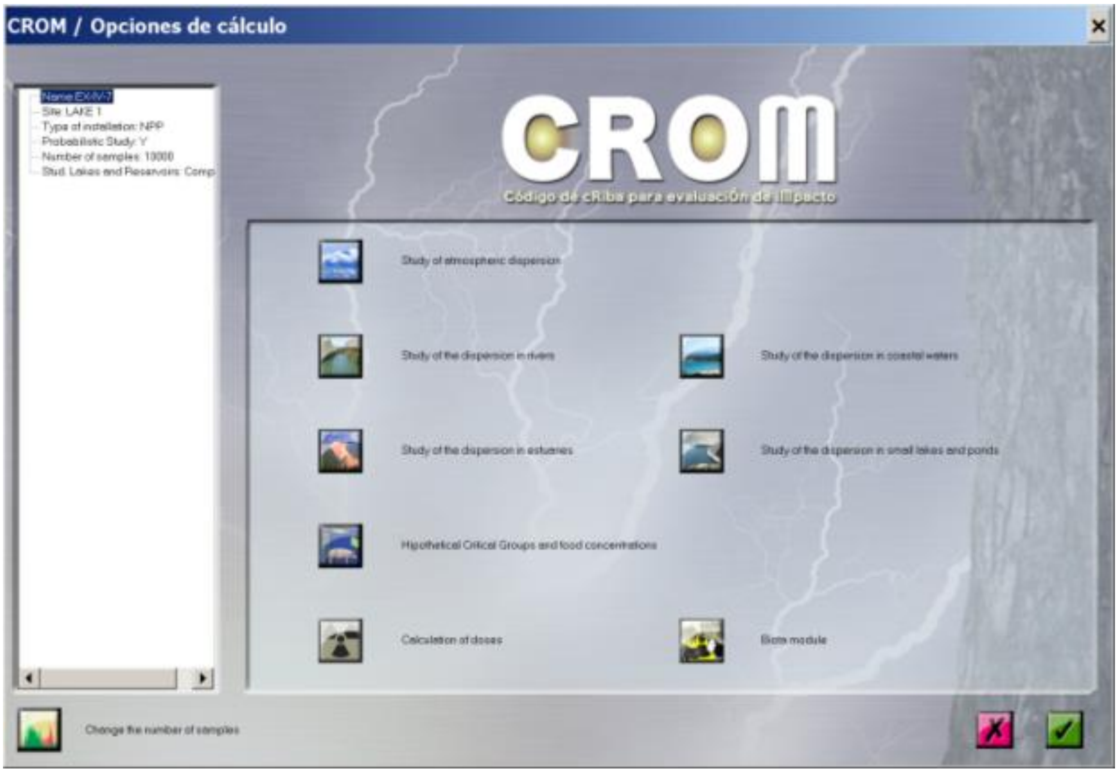

Fig 1.- Main screen of CROM8.

This new version of the code incorporates the dispersion models included in the SRS19 (IAEA, 2001). Some of the parameters needed for the integration, for instance DCCs, which have been recently revised in the ERICA Tool, have also been included in the database of the code, comprising 163 radionuclides for humans and 63 radionuclides for biota (the default radionuclides from the ERICA) in total. CROM8 can therefore calculate activity concentrations in the environment using the SRS19 dispersion models and then estimate effective doses to humans and absorbed doses to biota, via different modules within the one code. These changes to the code, therefore allow a complete integration of the approaches for radiation protection of biota and humans.

Certain functions that are available in the full version of the ERICA Tool have not been implemented in CROM8. These functionalities are the: EMCLs, 'Add organism' and 'Add isotope functions, UFs and sensitivity analyses. The main features of the ERICA Tool, not completely included in CROM8, are:

- Tier 1 applies Environmental Media Concentration Limits (EMCLs) with the user only needing to enter a media activity concentration. EMCLs are defined as the activity concentration in the selected media: soil or air (H, C, S and P only) in terrestrial environments, water or sediment in aquatic environments that would result in a dose-rate to the most exposed organism equal to that of the selected screening dose-rate. This EMCLs are calculated using 95th percentile transfer parameters whilst assuming the most exposed occupancy for each organism type. They are used as a simple means of making risk calculations with the minimum requirement for input information.

- Tiers 2 and 3 calculate the dose rate for each Reference Organism for each radionuclide included in the assessment. If site specific data are not available, the Tool contains concentration ratios and sediment-water distribution coefficients (both with associated pdfs) to predict organism and water or sediment activity concentrations as required. Dose rates are then estimated using the Tools database of dose conversion coefficient (DCC) values for all default radionuclides and organisms. The DCCs are split into alpha, low gamma-beta (< 10keV) and high gamma-beta (> 10keV) radiations.
- An "Add isotope" function is available in Tiers 2 and 3), where the user has the option to derive DCC for any radioisotope included within the electronic version of ICRP-38 (ICRP, 1983). The function (Ulanovsky et al., 2008) generates DCCs for all reference organisms (in all 3 ecosystems) using the same configurations used in the calculation performed for the ERICA list of radionuclides, i.e. source depth and positioning of the source relative to the target etc..
- Tiers 2 and 3 also contain an "Add organism" function, where users can specify their own dosimetric geometries (essentially represented by ellipsoids of specified relative dimensions and masses) and thereafter generate bespoke dose conversion coefficients.
- In Tier 2 uncertainty factors (UFs) are used to provide conservative estimates of environmental risk. Uncertainty factors are intended to provide an approximation of high percentiles risk quotients (RQ - defined as the ratio of the estimated whole-body absorbed dose rate to the screening dose rate) and are defined in the ERICA Tool as the ratio between the 95th, 99th or any other percentile (above the expected value) and the expected value of the probability distribution of the dose rate (and RQ). Further information concerning the details underpinning the derivation of UFs for the ERICA Tool and their suitability for characterizing parameters used in environmental risk assessment can be found in (Avila et al., 2014).

It was considered inappropriate to use EMCLs in CROM8 because the intention (by the developers) was to provide the assessor with explicit information on doses to humans and wildlife. However, default values included for biota assessments are based in 85% predictions, therefore comparable to Tier 1 in ERICA Tool. All other functionalities described above were considered to be of a specialised nature, i.e. might only be foreseeably applied in cases where detailed site specific environmental impact assessments were needed, and were therefore evaluated as being out of the scope of CROM8.

5 Quality Assurance

A continuous QA of the CROM code is carried out by CIEMAT, in collaboration with several other organisations (RPD-HPA, IAEA, ARN, BfS and others). Similarly the ERICA Tool and its databases are QC'ed by the developers (Facilia, NRPA, NERC-CEH, and the University of Stirling).

As part of the STAR project, BfS conducted a quality control of the biota module as implemented in CROM8. With an automated test code, the output of CROM8 was checked for validity. The calculations (mathematical equations) were checked as well as the parameter database. The parameters in the CROM8 output files were compared with values from a reference ERICA Tool database. The test cases covered a satisfactory portion of the parameter database.

The bugs found in the processes of quality control were solved, as well as problems found by participants in international projects such as the IAEA MODARIA programme.

6 Plans for future developments and maintenance

The next generation of the CROM code will be entirely new and will be named CROMERICA. This code will implement the revised models of the IAEA (i.e. replacement to SRS19), the updated version of MS3.3 and advances in the parameters in the ERICA Tool (note the IAEA approach will do some aspects of the wildlife assessment somewhat differently to the current ERICA Tool). This new tool will implement state-of-the-art approaches for improvements in performance, usability and maintainability.

The fundamental design requirements were agreed upon by WP3 participants of STAR. CROMERICA will be developed following these requirements:

1.- Calculation modules should not contain parameters in the code.

2.- All parameters should be included in readable format files (i.e. xml or txt formats), not using any predefined database.

3.- Input and output files, as well as intermediate calculation files, must be in readable format files (xml or txt formats).

4.- Each module should be developed in a way that can be compiled separately from the other modules.

5.- A Graphical User Interface must be developed in such a way that it creates readable format files (txt or xml) which serves as input for the modules.

CIEMAT will have overall responsibility for keeping the final version of each module and assuring an adequate quality of any new code programmed by third party contributors.

The new code is being developed in C++, but other commonly used programming languages can be used and will be supported for the development of new calculation modules, provided the input and output data formats correspond with the guidelines. Plain text files (txt) or eXtensible Markup Language (xml) format files for storing model parameters, communication between modules and for input and output files will be used. The new code is programmed for multithreading calculations and will be supported for common platforms (e.g. Windows and Linux machines running withx86 processors). These features will allow a separate QC of the source code and the parameters and the integration of revised models by expert coders if needed.

CROMERICA will maintain all features of CROM8, including the biota and human integration, uncertainties calculations or graphical capabilities, while following a design concept which allows for easy extension, quality control and maintenance. The final product will be a tool which can be further expanded by community developers, for including their own models and creating new user interfaces. This creates a flexible dose assessment platform which can be further expanded by new users for including their problems. An alpha version of CROMERICA will be presented at the final event of STAR in June 2015. STAR is funding the generation of a Graphical User Interface which contributes to the development of a user friendly tool. The CROMERICA development will continue by CIEMAT beyond the STAR project.

Plans exist for organizing user and developer courses in a regular way, where basic capabilities for performing impact assessments using CROMERICA and/or information for developers who want to include new modules, will be provided.

STAR appreciates the collaboration of the IAEA in these planned activities.

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