Harmonizing Domestic and Reference Software Tools for Nuclear Accident Consequence Assessment

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1 Introduction

One lesson drawn from the Chernobyl accident (Ukraine, April 1986) has recognized the importance of an *internationally*-shared availability of norms, methods and tools to characterize abnormal nuclear events; design prompt response measures commensurate with the potential off-site, including transboundary consequences of such events; monitor the evolvement of the radiological situation over the exposed territories in the medium- and long run; and proportionally adjust and maintain a sound management of the crisis aftermath. The experience gained has clearly demonstrated the need to develop and secure a widespread installation of an internationally-accepted, comprehensive Decision Support System (DSS) for radiological emergency management, capable of finding a broad application all-across Europe. It is in this context that Project RODOS (*Real Time On-line Decision Support System for Off-Site Nuclear Emergencies in Europe*), [1] has been commissioned within the Radiation Protection Research Action of the European Commission's Nuclear Fission Safety Program.

In pursuing its goals, the RODOS Management Group has actively promoted an early awareness on the importance of a comprehensive commitment of all constituents in the very development of the system and in the customization of the tools it offers, to fit national variations as far as data availability, legislation, practices, and culture. On this working assumption, IFIN-HH has deployed a proportionate effort to develop and maintain a domestic counterpart to its RODOS-related activities. It took the form of a standing, hands-on self-training in developing a variety of decision support tools drawing upon the current local background and experience, and looking at what was progressively thought to be the most relevant pieces of knowledge, methodology, algorithms, and code design styles available in the open literature. One purpose was to offer the pertinent regulatory and emergency response authorities, at each phase into the project, interim yet convincing demonstrations on the value and feasibility of having available practical tools to guide, assist, and satisfactorily document response decisions in the event of a drill-, or no-drill situation. Eventually, the core of the toolkit as described took the form of a coherent software package, domestically known as NOTEPAD. To compare NOTEPAD's performance against RODOS reference results, the *Total Effective Dose Equivalent* (TEDE) and the *Commited Dose Equivalent to Thyroid* (CDE THYR) have been selected in view of their direct relevance in scaling the sheltering, evacuation and iodine administration, countermeasures.

2 RODOS and NOTEPAD

RODOS is designed to assist decision-makers throughout all the conventionally-defined phases of a nuclear accident – from the Early Phase to the Late Phase. The conceptual architecture of RODOS (Fig.1), involves three types of subsystems:

- *The Analysis Subsystem* (ASY), consisting of modules that processes incoming data and forecast the location and quality of contamination including its temporal variation. The main module is based on the ATSTEP - code [2] using a near-field (ca. 50 km in radius) segmented plume model.

- *The Countermeasure Subsystem* (CSY), consisting of modules the output of which suggest possible countermeasures, check these for feasibility, and calculate the expected benefits in terms of a number of attributes (criteria). The main module here is EMERSIM [3], which estimates radiation dose equivalents for different periods (from 24 hours to 50 years), on different body organs, and in either open space or under shielding conditions. The system takes into account the adoption or absence of short-term countermeasures, such as population sheltering, evacuation and iodine tablets administration.
- *The Evaluation Subsystem* (ESY), consisting of modules that rank countermeasures according to their potential benefits and preference weights provided by decision makers, thus providing for the design of sound response strategies.

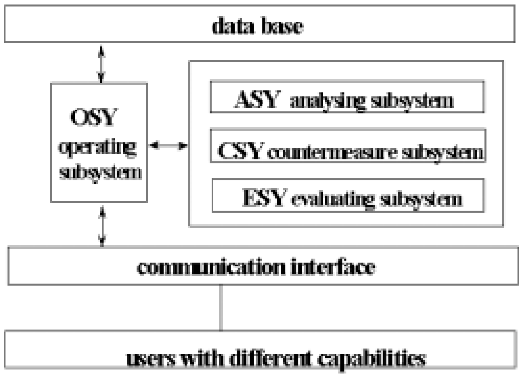

Figure 1 Conceptual architecture of RODOS.

In contrast, NOTEPAD is a shorthand, electronic version of some popular, in the trade, 'Response Technical Manuals' – in particular the *RTM - Response Technical Manual* series [4] by the United States Nuclear Regulatory Commission (U.S. NRC), and its international counterpart, *The RTM-95 International Technical Response Manual* [5] that observes norms and practices recommended by the International Atomic Energy Agency (IAEA). NOTEPAD's concept has originally been developed and tested at the U.S. NRC Headquarters in Rockville, Maryland, under the code-name ROBOT – for *Rule-Oriented Basic Operational Tool* [6], thus being reflective of the approach and attitude prevailing in a regulatory agency driven by firm legal mandates and liability bounds to go by simple, robust, verified, and easy to apply solutions to the inherent complexities of a nuclear accident with potential off-site consequences. In that, NOTEPAD attempts to put together in a coherently operable kit several tools that were proved to be of primary need and consequence in a radiological crisis management.These include:

1. A *Scenario Machine*, consisting of:

- A *Source Term module*, relying on a *Radioactive Inventory* sub-module, and a *Source Release Diagnose* sub-module. Radioactive inventories can be obtained, under standard assumptions, for (i) nuclear reactor cores, (ii) power reactor coolant; and (iii) isotope-based (accidentally) open radiation sources. Effective source releases to the environment (the 'Accident Source Term') are diagnosed based on plant status during accident sequences (the 'scenario approach'), taking into account the radioactive inventory corrected for shutdown time; the core release fractions for 155 fission products of outstanding interest in an off-site emergency; the natural (e.g. depletion by containment holdup, plate-out) and engineered (e.g. sprays, suppression pools, filters etc.) plant reduction factors depleting the core release on its way out to the environment; and the effective emission fractions, reflective of the actual containment condition (design leaks, isolation failure, catastrophic breach).

- A *Meteo* module, offering a convenient interface for correlating wind speed and cloudiness in order to infer the atmospheric stability class; specify plume centerline height category (ground or elevated);

specify the weather category (no precipitation, precipitation); and selecting the reference dispersion system (e.g. Karlsruhe-Julich, Brookhaven, St.Louis etc.) that fits the terrain roughness of the exposed territory; and, on this basis, call to use the consequent dilution factors and dose-adjusting factors.

2. A *Dose-Effect Assessment Machine*, consisting of:

- A *Source-to-Dose Evaluation Facility*, distributed over several dedicated modules: a *Dose Scanner* giving 9 varieties of expected doses at the position of the mouse cursor on the map of the exposed territory; a *Dose Mapper* overlaying on maps the respective isodose lines for user-chosen relevant dose levels; *a Quick Dose Evaluator* directly linking the source term to the dose at user-given distances, downwind on, and crosswind from the atmospheric transport axis.
- A *Field-to-Dose Evaluation Facility*, that computes the relevant doses starting from results of field measurements in terms of airborne activity concentration (μCi/m^3) and deposition (μCi/m^2).

3. A *Derived Response (Intervention) Levels (DRL/DIL) Machine*, designed to compute and report the time-evolvement of the DRLs for several chief countermeasures, including *sheltering*, *evacuation*, *administration of stable iodine*, and *food and feedstock restrictions*, taking into account the decay and ingrowth of the released fission product nuclides, over times stretching from a few hours to one year or more.

3. The Comparison Framework: Accident Scenarios

On the occasion of the nation-wide nuclear alert exercise "OLTENIA '99", organized by the Romanian *Central Command Unit for Nuclear Accidents and Fall of Extra-Atmospheric Objects* (CCANCOC) concerning a hypothetical nuclear accident at the Kozloduy Nuclear Power Plant in Bulgaria, on the Danube River, IFIN-HH Bucharest was called upon to provide the accident scenario, and subsequently participate in the accident consequence assessment and the simulated crisis management. In the process, a comprehensive set of source terms and meteo scenarios was generated using NOTEPAD, also in consideration of the fact that the current RODOS version does not yet include a source term machine of its own.

Taking the opportunity, RODOS and NOTEPAD were run against identical scenarios from the offer described. For comparison purposes, in the evaluation of doses the number of radionuclides was limited to 15 (^{85}Kr ; ^{86}Rb; ^{89,90}Sr; ^{132} Te; ^{131,132,133,134,135} I; ^{133,135}Xe; ^{134,137}Cs; ^{140}Ba) due to the current requirements of the RODOS system.

Code runs have been conducted for wind velocities of 2.1 m/s and A through F Pasquill stability, no precipitation assumed.

The following reference doses were sampled and compared: CDE THYR, and TEDE.

4 Results

To illustrate, here is a representative accident scenario:

> A loss of coolant by breaks and leaks is assumed, ensuing a catastrophic failure of isolation in the accident localization volume due to structure’s pressure relief valves getting stuck open by overpressure. The reactor core remains uncovered for 30 min., so that a fast temperature rate (1C/s) brings the core temperature over 1650^{o}C. The core melts through the vessel before the start of the release to the environment. The aerosols and radioactive particles are partially retained only by natural depletion into the plant structures, for a holdup time less than an hour, before escaping to the atmosphere for an effective duration of 30 min. The total activity released to the environment is thus found by the code to be Λ = 1.9x10^8 Ci, representing about 10% of the inventory, and indicating a severe accident.

On these working assumptions, the RODOS/NOTEPAD ratios for CDE THYR and TEDE were computed over a range of 2 to 25 km, with a 1 km-step. An interpolation of the ratios was performed using cubic B-Spline and Bezier functions.

Figures 2 and 4 render CDE ratios, while Figures 3 and 5 bear on the TEDE, for A and D classes of atmospheric stability.

One can see that, compared with RODOS, NOTEPAD-issued values would tend to appear larger. The apriori suspicion that a relatively rigid, rule-based code like NOTEPAD, ignoring the subtleties of a detailed atmospheric dispersion modeling would generate overconservatism was thus confirmed. There is also little doubt that differences between RODOS and NOTEPAD in the dose conversion factor (DCF) databases, as well as in method-related factors bearing on the time-averaging the quantities involved, and accounting for the nuclide decay and ingrowth would also contribute to the differences in the absolute figures. Equally remarkable is, however, the *relatively stable pattern of the NOTEPAD-TO-RODOS differences*. It is believed that, in practical terms, the latter is even more relevant than the numerical discrepancy, thus providing, in principle, *for a feasible, systematic conversion of NOTEPAD results to RODOS results*.

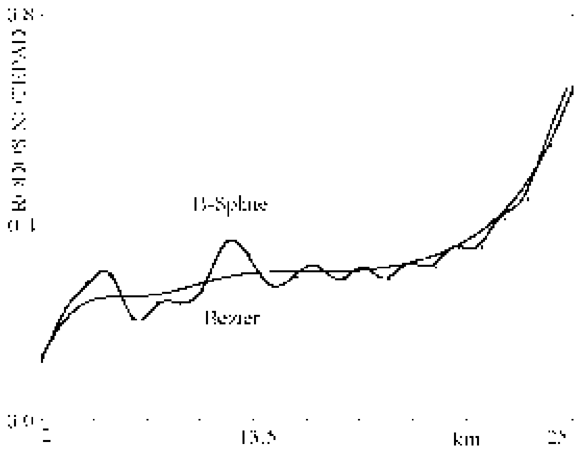

Figure 2 RODOS/NOTEPAD Ratios for CDE (A category).

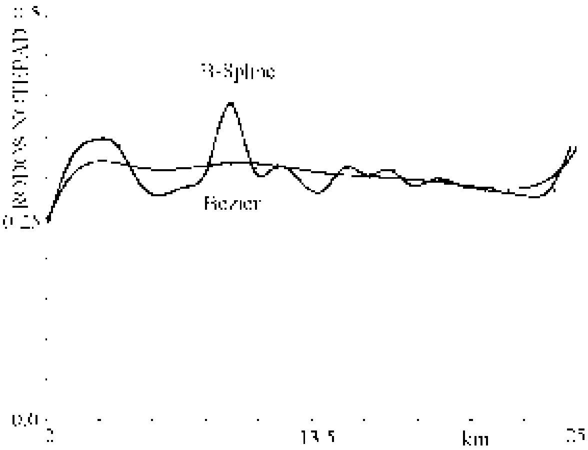

Figure 3 RODOS/NOTEPAD Ratios for TEDE (A category).

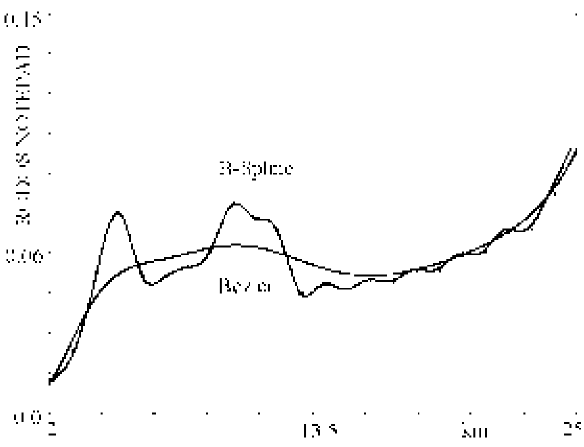

Figure 4 RODOS/NOTEPAD Ratios for CDE (D category)

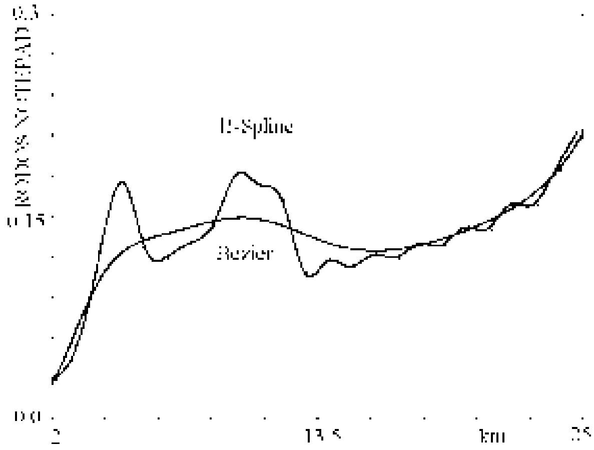

Figure 5 RODOS/NOTEPAD Ratios for TEDE (D category)

This finding feeds the notion that NOTEPAD, as a low-cost, portable, complementary to RODOS, and interim tool, may be assigned operative missions in drill/no-drill situations, provided a robust and reliable normalizing method is fully developed, based on the approached as reported. Key factors are (i) a satisfactory coverage of the source term and meteo scenarios spectrum; and (ii) a clean interpolation of the normalizing factors – e.g. based on B - Splines and Bezier smoothing.

5.Conclusion

During the development of the *Real-Time On-Line Decision Support System for Nuclear Emergencies in Europe* (RODOS), both the traditional and innovative DSS tools may still perform useful functions within the radiological emergency preparedness process at national levels. One case in point reported in this paper – the code NOTEPAD would demonstrate that similarity patterns may be obtained via code intercomparison exercises involving comparable accident sequence scenarios, resulting in normalizing factors that make feasible a conversion from one code output to the other.

As a rule, codes like NOTEPAD are designed to run on low-cost *portable* hardware, normally available with *local* crisis response centres and *operative* field cells to preliminarily project consequences of abnormal nuclear events and steer the required prompt action *in the early phases* of accidents. On the other hand, the RODOS system is designed to provide *reference, comprehensive and authoritative assessments* to assist the decision makers in *national* centres of crisis. As a graphics station-based complex software, real-time fed with data incoming through communication channels from the national/regional meteorological networks, RODOS is inherently a *fixed*, *strategic* facility meant to manage *all phases of a radiological crises* over, perhaps, several years from the abnormal occurence. When quality-assured via appropriate harmonization procedures, the complementarity of the two sets of tools is believed to be productive.

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