ETH - RISK: a Pilot Knowledge and Decision Support System for Nuclear Power Accidents Emergency Management

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Abstract:
ETH-RISK is designed as modular, expandable, articulated, GIS- oriented platform, capable to accomodate and test a variety of models- mathematical and logical- normally concuring in the risk and accident consequence assessment as applicable to nuclear power plants. The current version of the software, drawing upon a preliminary concept developed by one of the authors (D.V.), combines expert system and GIS features into an early-response-oriented Knowledge Based and Decision Support System. It also combines pre-digested knowledge and casuistry with ad-hoc analysis to diagnose abnormal events, evaluate the amplitude of the entailed environmental contamination and potential health effects, and have these mapped together with the zones of recommended intervation, including the points of minimum risk. ETH - RISK is believed to hold good potential for steering a many-folded development: towards a DSS, computer assisted learning and expertise instrument, transparent to mitigate several expert-to-decident communication problems in Emergency Management.

1. INTRODUCTION

The archetypal severe nuclear accidents, Three Mile Island and Chernobyl have revealed the singular importance of the availability of Knowledge Bases and Decision Support Systems (KB-DSS) for an efficient emergency planning and management of nuclear crises. At the origin of this situation is the demanding nature of the main task in severe accidents' management; to cater for masses of people in distress in manners that would not add too much to the hardships already confronting them. A number of factors would further stress this deontological must, such as:

i) the fact that no two accidents are exactly alike, abnormal nuclear events featuring a variety of possible initiators and sequences that are rich in potential bifurcations, commensurately with the inherent complexity of the nuclear technology;

ii) the unusually wide margins of uncertainty within which measurements, diagnosis and prognosis must carve a path to decisions on protective/ corrective action, to the extreme extent of talking the consequences of an accident the source term of which may never be actually known - the least in its most critical, early phase; and betting high on a whimsical meteorology;

iii) the crucial importance of the time factor in deciding upon, and implementing the early countermeasures (e.g.sheltering, administration of stable iodine, and evacuation);

iv) the comparable importance of the space scales, and site specificity insofar as terrain's relief, canopy, climatology, demography, exposed property, social habits, behaviour and reactivity etc. One difficulty bears on the quest for a near-real time response from the advisory machines on the one hand, and the need to decently account for complexities including e.g. source terms, a variable in time and territory meteorology, and a terrain of tortuous relief and patchy canopy, demography.

As proven in actual practice, this has a counterpart in communications (man-machine and man-to-man). Recent analyses /1/ have concluded that such conflicting demands "cannot be fully resolved, but the approach chosen should be an acceptable compromise between the requirements for scientific rigour, flexibility and easy adaptation to user's needs". ETH - RISK is a computer software for accident consequence assessment, KB and GIS oriented platform capable to accomodate a variety of mathematical and logical models in risk and NPPs accident consequence assessment. The software interfaces its User to a Knowledge Base consisting of (i) rules derived from knowledge pre-digested in Accident Response Manuals (ARM) issued by nuclear regulatory bodies and/or utilities; and (ii) algorithmic expressions of logical and mathematical models of the phenomenology typically accompanying a nuclear accident, from the occurence of an initiator down to a radioactive release, its environmental dispersion and consequent effects. ETH-RISK does not ignore the existance and continual improvement of emergency management software. The contrary- the exercise to develop this software is precisily motivated by an awareness on the issues that so far prevent the adoption of any single DSS as a universal, crisis management tool. The coverage: of time and space scales (early/intermediate/late accident phases, near site/regional assessment):of site and environmental typology (the source term: reactor, waste repository, UF6, fire/ non-fire source, transport; singular burst/protracted, long duration release: release including/not including activities); ii) trading off DSS complexity vs. practicality, accuracy vs. near-real-time capability; iii) communications quality (expert-to-layman-decident, and the public at large; man-to-machine and vice versa); iv) compliance with national / international standards, norms, practices, behaviour, legislation; v) deontological constraints: (dose minimization vs. as-low-as-reasonable adequate intervention; having the machine advising, never deciding).

ETH-RISK is an experiment; it accomodates postulated/ simulated source terms, environmental dispersion under a variable in time and space meteorology, complicated terrains and aims at enhancing event diagnosis capabilities and heuristic modelling in line with currently perceived needs in the Emergency Management trade.

2. ETH-RISK's STRATEGY

ETH-RISK's philosophy and strategy stem from the paramedical approach to intervention in case of individual - collective health crises. At the core of its spirit is a handful of common sense principles, such as:

Rule a: First aid comes first, the full clinical investigation and intervention - later.

Rule b: Base first aid on fast anamnesis - if feasible -, and fast symptom analysis, both conducive , yet not iretrievably commital, diagnosis.

Rule c: Move fast. Have a limited yet proven inventory of relevant diagnostics ready for use, together with corresponding sets of "golden rules" that may ease the crisis till more profound measures can be initiated.

Rule d: Make all steps taken amenable to the understanding and co-operation of all actors involved;

Rule e: Base your tool kit on pre-digested knowledge; ***experience;*** and ***expert judgment.***; make extensive use of response manuals; considered "best guesses"; postulated prognosis (scenarios); simulation exercises; heuristic associations; accumulated casuistry.

Rule f: Adopt a deontology of *As Low as Reasonably Adequate (ALARAd?..)* intervention; until full clinical investigation and lab analyses are properly done, chances of ill-advised intervention remain high, which may synergistically amplify the costs - human, financial and material - of crises.

Rule g: Keep yourself in good fittness -- which also implies keeping your tool kit up to the state-of-the-art. ***Don't trust low probabilities when risks are high: try and anticipate as many "worst cases" as imaginable/tractable. The least expensive and also safest way towards a "near-real time" tool is to remove the bulk of work from the crisis time into the training time.*** There is such a thing as the "crisis stress sydrome", that is likely to cut emergency managers' abilities by sensible fractions.

Observation : Working in anticipation of the worst is one safe way to shield yourself against the crisis stress syndrome.

Comment 1: ETH-RISK is an early-intervention oriented tool meant to offer guidance and support to managers' reaching minimally informed decisions on the most time-sensitive action normally expected in an off-site consequences entailing nuclear accident: activation of crisis management entities; assuming of legally-enforced postures and action station by the chief actors; early alert; and application of early countermeasures.

Comment 2: ETH-RISK would operate on the principle that, in the event of a severe nuclear accident, everybody in an undeterminedly wide proximity of the source would get something out of the release. Problem is who is likely to get more, where and when. ETH-RISK shows field operators where to act first, when, and how. ETH-RISK is primarily after : the Most/Least Exposed Areas in a target-territory; the Paths of Minimum Exposure; *de minimis* Alert terms of reference, such as cloud's Estimated Arrival and Exit Times and Maximal Expected Local Activity Excursion; thematic mapping of Zones of Recommended Application of Early Countermeasures, and of potential health effects (risks).

Comment 3: ETH-RISK (i) offers the User an interactive, expeditious input machinery; (ii) sufficient explanatory assistance at run time; and (iii) pictorial, expressive and readable outputs as far as feasible. Most ETH-RISK outputs are in form of maps - of contrasting exposure, contamination, and intervention zones, super-imposed on geographical maps that may readily be rendered in a 3-D perspective, as probably one of the most informative and intelligible manner to address laymen decidents and guide field operatives.

Comment 4: ETH-RISK would also try to show itself sensitive to human nature. It cross-examines its partner, confronting him with human's appraisal/reasoning flaws, incongruences, inconsistencies etc. amounting to conflicting diagnostics. It will always leave final decision to its human counterpart. Reiterations, and the quest for alternatives are built in the human nature; ETH-RISK would considerately provide for these, too.

Comment 5: ETH-RISK is a modular, open structure that may - and will - assimilate in later phases of its development components that will go deeper into the accident's time to its Intermediate and Late phases, dealing with food restrictions, health effects categorizing and assessment, assessment of economic losses, cost - benefit analyses of countermeasures effectiveness, projections and planning of corrective actions for environmental and property reclamation etc.

Comment 6: The long way of ETH-RISK's towards growing into a full operational tool would take interested developers and users through much model refinement and augmenting; intensive testing, aiming at error trapping and improved logical articulation; site-customizing and validation through field experiments.

Comment 7: The ETH-RISK exercise has taken up a principle of non-intrusion: pilot platform to put on trial various concepts in Emergency Management.

3. ETH-RISK's MODELS

To implement its early-intervention oriented strategy, ETH-RISK selectively embraces two conventional approaches, namely:

i) The dose-oriented approach, geared to the effective determination of dose rates and committed doses to critical groups, relying on the appropriatenes and completeness of Dose Conversion Factors (DCF); and

ii) The derived intervention levels approach, geared to the determination of time-integrated concentrations in air and time-integrated depositions, and the expeditious comparison of these with the intervention levels recommended by the IAEA for such directly calculable and measurable environmental impact quantities (Derived Intervention Levels-DIL). The uncertainties and many sources of error would then shift from the DCFs to the DILs, particularly having in mind the delicate task of site-customizing DILs.

Other distinction in ETH-RISK is between logical models and mathematical models. While the logical models are algorithmic expresions relying upon the Boolean algebra and IF...THEN...ELSE rules, of the fault and decision trees descriebed in Accident Response Manuals, the mathematical models would capture in evolution-and other equations the release of radioactivity, its environmental transport and dispertion, and the lines between the environmental contamination and the recommended interventions zones, as well as the dose distribution and respective, expected health effects. The interweaving between the above criteria is rendered in Figure 1. A distinction is made in ETH-RISK, between: i) consequence assessment in the near-range around release sources; and, ii) consequence assessment at regional scale. The main differences concern the assumptions on the weight the terrain might have in driving the dynamics of the radioactive clouds/plumes: high and decisive for the near range that is dominated by the notion of termo-hydro-dynamically distorted flows, and less consequencial at regional scale - where mesoscale circulation and dispersion would call the rules and odds.

3.1. Logical Models in ETH-RISK

Figure 2 is self-explanatory; the various expressions may take across a process that starts with the factual realities of life and ends up into the Analyst/ Decident's mind, via the DSS; the crisis stress syndrome normally striking Emergency Managers in no-drill situations. Managers are prone to making erroneous use of the intricately articulated knowledge in Manuals, generally based on fault tree analyses, and/or may need more time than acceptable to reach the right verdict on events and identify the respective required actions. Facing these, an automated exploitation of Response Manuals have appeared as the next natural step with streamlining DSS sessions by further transferring part of the analysis effort into the preparedness area. The automated diagnosis of an abnormal event in a plant, followed by an automatic verdict on what action should be immediately taken, was termed a 'Synthetic Diagnosis'. The implementation of the Synthetic Diagnosis scheme required i) a convenient algorithm to articulate the logical values along and across the fault trees described in ARMs, and ii) a user-friendly code to make algorithm(s) work. The algorithms made extensive use of IF...THEN...ELSE clauses and pertinence matrices, while codes tried and reflected the typical human perception on how a diagnostic can logically be reached - that is, through anamnesis. The first steps into an ETH-RISK DSS session comprise:

i) A statement from the KB-DSS Operator, given in natural language, on whatever (apparently) happened that made him activate the KB-DSS.

ii) A message analysis by the Machine searching for relevant keywords, either directly belonging to the trade's idiom (e.g. 'pump', 'coolant', 'valve'), or suspected to be reflective of crisis situations ('casualties', 'loss' etc.). A ***de minimis*** set of keywords was provided, in the Machine's Basic Lexic bank.

iii) An anamnesis of the Operator by the Machine, in consideration of the message received. In its current version, the code would start firing pertinent questions to the Operator. The pre-formatted questions are reflective of the investigative logics of the RTM-91 Response

Technical Manual Vol.1, Rev.1 - April 1991 by the US Nuclear Regulatory Commission /2/. Accepted answers are 'yes', 'no', or 'don't know'. Different key-words were contextually organized in the structured lexic so that returns to the same machine 'suspicions' were made possible. Graphic examples may be 'pump', 'line', 'valve', 'pressure' etc. that would trigger related, yet not necessarily identical querries. The more fuzzy a term, the higher the number of queries raised by the Machine in its trail - to the extent that one of the most unclear yet disturbing word, namely 'problem' is bound to trigger almost all the available questions in stock, till the answers would zero-in upon a clear diagnostic. Cross-examinations are then conducted by the Machine using alternative approaches described in ARMs,.to consolidate the diagnosis. In the process, conflicting diagnostics may occur on the account of the near-impossibility to develop a simple and full-proof speech / text analysis algorithm. Such conflicts should be resolved by the Human Factor only; ETH-RISK should advise, yet never decide.

iv) Once a synthetic diagnostic is reached, the machine would deliver this in the form of an alert grade. Possible grades are:(1) Notification of an Unusual Event, (2) Alert Status, (3) Site Area Emergency, or (4) General Emergency. Each grade would attach a number of response recommendations and rules of conduct, on-site as well as off-site, for accident managers in different positions. Room for 'Events below Scale' was also reserved.

3.2 The Mathematical Models in ETH-RISK

Mathematical models in ETH-RISK originate in the general notion of transport phenomena. A tractable solution to the flow motion in complex terrain was designed; it was based on a heuristic parametrization of the original Navier-Stokes equation. Key to modelling the complex terrain's influence on flow motions was the introduction of the terrain-distorted "pressure" field parameter. A tensor is coupling the "pressure" gradient components features and a "plan" component that is proportional with the local angle between Sun's direction at each moment and the normal to the terrain in the respective spot. An inversion lid oscillating between midnight and mid-day and small eddy turbulance were also introduced in the model. It is precisely the interplay between the inversion effects and the driving forces induced by the insolated terrain that result in determining released puffs trajectories. Flow's large eddying in hydrodynamic cavities, blockin, deflection, "chimney" and "canion" effects, and other characteristic behaviour is well acounted for by the model, under the control of essentially two parameters- a characteristic length, and a friction-related quantity that are to be adjusted according to the rugosity of the terrain. To descriebe puff dispersion in the trajectory model, a fractal structure of the released clouds was assumed, in the same sense that around the main puff center evolving along its trajectory mini-puffs are generated in three dimensions following a gaussian spatial distribution with Doury coefficients. In turn, each minipuff features itself an identical, interior, gaussian distribution. Ground reflection and deposition are provided for in the model, in latter being discussed in terms of frequency and velocity. The effect of precipitations is also accounted for. This near-range trajectory puff model generated in a probabilistic mode-assuming gaussian distributions of particle masses, wind directions and speeds around referance values, or in a deterministic mode, when release rates, wind directions and speeds are user-given. Wind rose distributions of wind directions can also be descriebed. A plume rise model is also incorporated. At regional scale a multiple straightline gaussian model of plume dispersion, or again a couple of puff models can be considered to obtain maps of time - integrated concentrations, time-integrated deposition on ground, intervention zones, doses and effects. This time models would rather use closed formulas for the integral solutions of the advecting-diffusion equation, integrated in time using K-Bessel functions. The dry and wet cloud deplation and deposition are all related to the Bonka and Horn approach, whereas for the gravitational setting a scheme proposed by Bridgmann and Bigelow was used. A fraction of plume's conformity with the terrain was assumed to take care of complex terrain effects at this much larger scale. An enhanced flexibility provides for griding in both space and time not only the eulerian wind field (direction and speed), but also the precipitations, the atmospheric stability, and the vegetation. Four point bi-variate interpolations are used in a pixel-by-pixel rendering of ETH-RISK's thematic maps.

3.3. Mixed models: Logical and Mathematical

Models in ETH-RISK are, unavoidably, mixtures of logics and mathematics; there is one section of the code package where the such mixture is of essence. It deals with accident source terms. SOURCE.ETH-RISK - is another expression of the Synthetic Diagnosis strategy as explained. Basically, it is a source term indirect diagnosis module that relies on plant condition analysis. Pictorial viewgraphs of five standard types of US reactors (PWR dry containment, PWR ice condenser containment, and MARK1, 2, and 3-contained BWRs) are called together with the most critical points that are prone to accidents with potential consequences. Affected

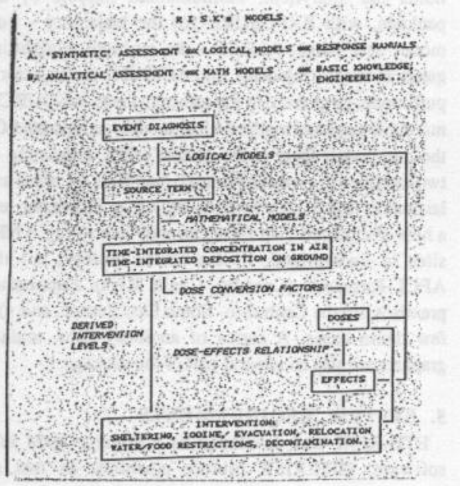

Figure 1

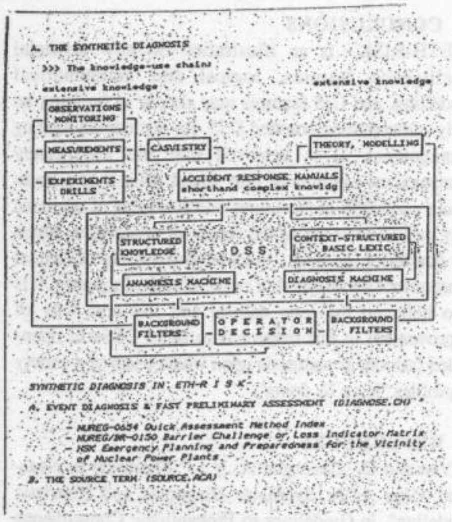

Figure 2

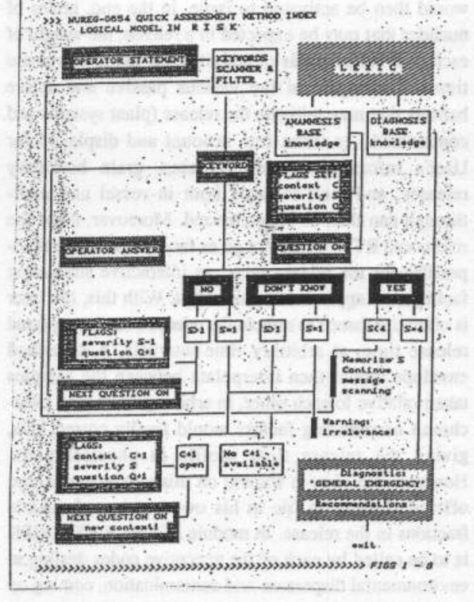

Figure 3

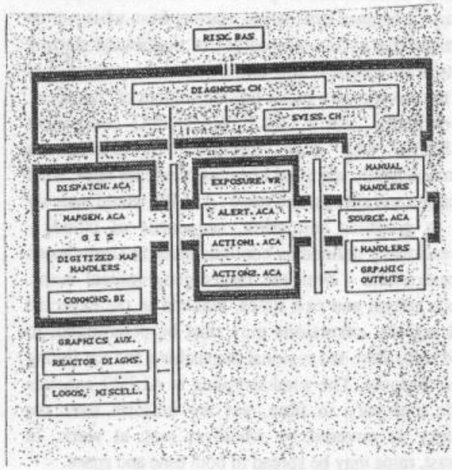

Figure 4

spots are to be marked on a move-cursor basis. The RTM's inference machinery that was cabled into the code would then be activated to issue, in the end, tables of nuclides that may be expected in a release, the weight of each, and summ totals of activity over expected release times. The logics of the various passive and active barriers that may mitigate the release (plant systems and containment) is taken into account and displayed for User's information. Gap releases, grain boundary releases, and melt releases both in-vessel and melt-through can thus be characterized. Moreover, since the referenced RTM would not go as far as to prescribe time-profiles for the release rates, an interactive simulation facility was appended to this effect. With this, the User is offered a chance to sample the release over the expected release time, at arbitrary time-intervals. A smoothed envelope would then interpolate between the samples taken relative to each other, in arbitrary units, and User-chosen normalizing factors would finally correct this, giving the release time profile in physical units. However, the User is warned on this circumstance, and offered chances to file in his own version of nuclide fractions in the release. In module SOURCE.ETH-RISK is to be called by each of the executive codes dealing in environmental dispersion and contamination, coming up next. An essential aspect about ETH-RISK is that, for its largest part, it is patterned in a GIS style. Figure 3 explains that only the components declared in bold case are operable. Several other aspects about code's facilities may be worthmention. One facility is for User to roughly determine the paths of minimum exposure during a presumed evacuation, starting from wherever on the map. If a sufficient number of distributed starting points is so tested, it will turn out that the paths would tend to converge to a rather limited number of "families", or corridors. An EARLY WARNING component (ALERT) was also designed. Working on deterministically specified histories of release rates, wind directions and speeds, and rains , ALERT would basicaly fire, in graphics animation, sequences of clouds - conventionally defined by contours taken at User-chosen concentrations - over the target geographical maps. Clouds arrival and exit times, maxima in the expected local activity excursions may thus be determined, to guide early alert, the regional dispatching and the timing of the response. The wind sampling in ALERT assumes winds that vary in time, yet are uniform over the territory as covered by whatever map at work. In contrast, rains may be spread in both time and space.

4. ETH-RISK's STRUCTURE

Figure 4 gives the ETH-RISK's modular structure. The upper floor (DIAGNOSE.CH, SWISS.CH) make the "synthetic diagnosis" section, the middle level-center holds the analytical, mathematical models of the package, with EXPOSURE for the trajectory - puff model near range, ALERT - the multiple straightline gaussian model (regional), and ACTION2 the trajectory-puff model (regional). In the executive area is SOURCE, mixing logical and mathematical models as indicated.On the middle-left level is the system's GIS, consisting of two facilities to generate numeric map files for relief and landmarks (roads, state borders, etc) a map dispatcher, and a host of digitized map files, currently describing i) NPP sites in Switzerland, ii) the Swiss teritory, iii) the AECL-Research (Canada) Chalk River Laboratory premises, iv) the Central-to- South East Europe, and v) a few demo cases. A series of ancillary files, mainly graphics are also an integral part of the package.

5. SYSTEM REQUIREMENTS

ETH-RISK was developed as a portable IBM PC-software. ETH-RISK prefers machines as fast as available. A coprocessor, whether independent or integrated into the motherboard (models 486 and up) is of essence, as is a fast clock. Users are advised to not even try ETH-RISK on anything below 33 MHz. Colors are of consequence with ETH-RISK.

6. CONCLUSIONS

ETH-RISK is an illustration on how artificial intelligence features, logical and mathematical modelling, and GIS features may concur in building an early - intervention oriented DSS for nuclear emergency management. It is believed that the Emergency Management community may found it itself at a point where good DSS architectures and strategies of response may prevail over the naked technical proccesses. Since the quality of the man - machine interface is of critical consequence for the quality of the DSS performance, it is also believed that one natural and low-cost way of improvement in this respect is to build DSSs in open-ended fashion, as platforms upon which users of a variety of profiles "learn by doing".

7. REFERENCES

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2.*** - US Nuclear Regulatory Commission (1991). RTM-91 Response Technical Manual. NUREG-0150, Vol. 1-2, Rev. 1, April 1991.