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Journal of Hazardous Materials 111 (2004) 45–55

Journal of Hazardous Materials

www.elsevier.com/locate/jhazmat

Decision support systems for risk mapping: viewing the risk from the hazards perspective

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Available online 26 April 2004

Abstract

Setting as central theme the response of stakeholders to the challenges and offers of *Risk Analysis*, the paper proposes an approach meant to facilitate risk communication: mapping risk from the hazards perspective—that is, emphasizing the consequence-related factor in the standard risk representations. A working demonstration is presented to illustrate the concept, in relation to a decision support system (DSS) design that has caught, over the past few years, the interest of several authorities and *forae* in Switzerland and elsewhere, providing for useful exchanges between the risk community and stakeholders from major industries, infrastructure operations, finances and other areas.
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Keywords: Risk mapping; Hazards; Decision support

1. Introduction

1.1. The challenge

The evident disproportion between the increasing performance and refinement levels of Risk Analysis, on the one hand, and the still limited depth and extension of its impact on the stakeholder environment, on the other hand brings to attention *risk representation* as a still pending issue.

It is uniformly recognized that risk would involve the *probability*, and the *consequences* of abnormalities on a relatively equal footing. However, the Probabilistic Risk/Safety Analysis (PR/SA) made headway with noticeable difficulty as a *practical* assessment tool, while audits—more often than not a preferred solution in assessing risks and their acceptability—would still lend the ear rather to *hazards*, and potential consequences of disruptive events ultimately measured in lives, and money, that seem to come closer to the common perception in comparison with statistical abstractions (see e.g. [1]).

The question is—would it be conceivable to design a manner of addressing risk by mainly relying on its hazards-related dimension (the consequences of abnormalities) while still observing some statistical discipline in the assessment?

1.2. The Approach

In mind with the view of the regulatory and emergency response bodies as prominent, target-stakeholders, one submits that a possible avenue towards enhancing their interest in risk as a whole is to

(i) link risk to *decision*, as a favorite activity in the respective environments;
(ii) address, indeed, risk issues from their favorite perspective—the *consequence* factor in the risk equation, as a projection of the *hazards* associated to the respective business; and
(iii) make the statistics *an implicit quality of the data employed*, as opposed to the explicit statistical nature of the *probability*, as either a factor in the risk equation, or a dimension in a standard Risk Matrix, or a Complementary Cumulative Distribution Function (CCDF) risk representation.

Two businesses featuring prominent, archetypal hazards were chosen as test-ground for this approach: *the nuclear power generation*; and the *chemical industry*. In both cases straightforward, quantitative risk analysis approaches based on *rules* derived from sophisticated mathematical models rather than on the models themselves, were called to work.

In the context, a 'rule' is understood as a, generally, simple algebraic and/or boolean equation deriving critically

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0304-3894/$ – see front matter © 2004 Published by Elsevier B.V.
doi:10.1016/j.jhazmat.2004.02.010

important quantities such as radiation-, or toxic doses from, essentially, averaged or otherwise *representative* dose conversion factors and scaling quantities (times, distances), or deriving decisions on countermeasures from, directly, derived intervention (response) levels. *Dose–effect rules* would then pave the way to expected *health effects*, and *property (physical) damage*, if/as appropriate, thus bringing *lives* and *money* into consideration. In this sense, the 'rules' tend to make a most effective shortcut to casuistry, and databases.

Apart from being relatively simple and effective, the rules would have, by definition, several other qualities of essence:

First, they are *accepted* by key factors in the risk management business, such as the regulatory, and the emergency response, authorities. As an expression of such an acceptance, the 'rules' are, more often than not, assembled in risk assessment *guidelines*, emergency response *manuals, procedures*, or other, similar documents issued by the said authorities. The *Guideline*- and *Technical Documents* (TECDOC) series by the International Atomic Energy Agency, *the RTM—Response Technical Manuals* series by the U.S. Nuclear Regulatory Commission [2], *the FRMAC Assessment Manual* series maintained by the U.S. Department of Energy with assistance from the Nuclear Regulatory Commission and the Environmental Protection Agency [3] make prominent examples.

The second merit is that 'rules' are more *readable*, or *intelligible*, and thereby more likely to be understood by laymen-stakeholders, than the models behind them.

Finally, far from ignoring the statistical dimension required in a risk analysis, the 'rules' *imply* it: key-quantities such as the dose conversion factors, the effective times of exposure, the derived intervention levels, the probit function coefficients, the critical, reference toxic indices like IDLH, TLV, STEL, etc. are all *averages*, or otherwise *representative* data collections as far as e.g. isotopic mixes, exposure time intervals, sets of circumstances (like weather conditions, subjects behavior under exposure), streamlining and simplifying assumptions, etc., thus being reflective of the quest for the 'most expected' occurences—which are always of a central importance to stakeholders. In other words, with the rule-based approach *statistics come into the play via the representativity of data, instead of the probability of events*.

The approach as described is aware of the fundamental, if apparently oversimplifying, query of the stakeholder: "*What is at risk, after all*?" For the answer be meaningful, it must be given in lives and money, spanning over hectares and hours. Consequently, the risk is to be projected, or 'mapped', in such terms.

2. Mapping risk from the hazards angle to make decisions

2.1. The framework

At the Laboratory of Safety Analysis of the Swiss Federal Institute of Technology (ETH) in Zurich, the concept as described was enduringly tested over the past decade in a variety of software configurations, on a variety of stakeholders. Projects like '*Risk and Safety in Technical Systems*', '*Risks in the Transportation of Dangerous Goods*', '*SESAM*', '*China Energy Technology Project*', '*DRM Tools*', '*Aids to Risk Assessment and Management*' (AIDRAM) were hosting the research, with cross-sponsoring from in-house and other resources that included the *Alliance for Global Sustainability* and the *Disaster Risk Management Institutes—World Bank*. A substantive interaction with stakeholders coming from the nuclear power generation, chemical industry, railways infrastructure, the automotive industry, the building materials industry, the finance and insurance system served as feedback support and marketing exercise [6].

The work that revolved around the concept of *open-ended, modular, customizable software platforms* has gradually encompassed an ever larger problematique. Eventually it came to include, inter alia:

Irrespective of customer-sensitive details, all the software that has been developed in the context described shared a common design: a collection of *applications* hosted on a *platform* made of *GIS libraries, data libraries*, and *knowledge libraries* (nuclear, chemical, engineering, etc.), managed, respectively, by a *GIS engine*, and a *database engine*.

Most of the software functions converged towards a single end: *the risk mapping, from the hazards perspective.*

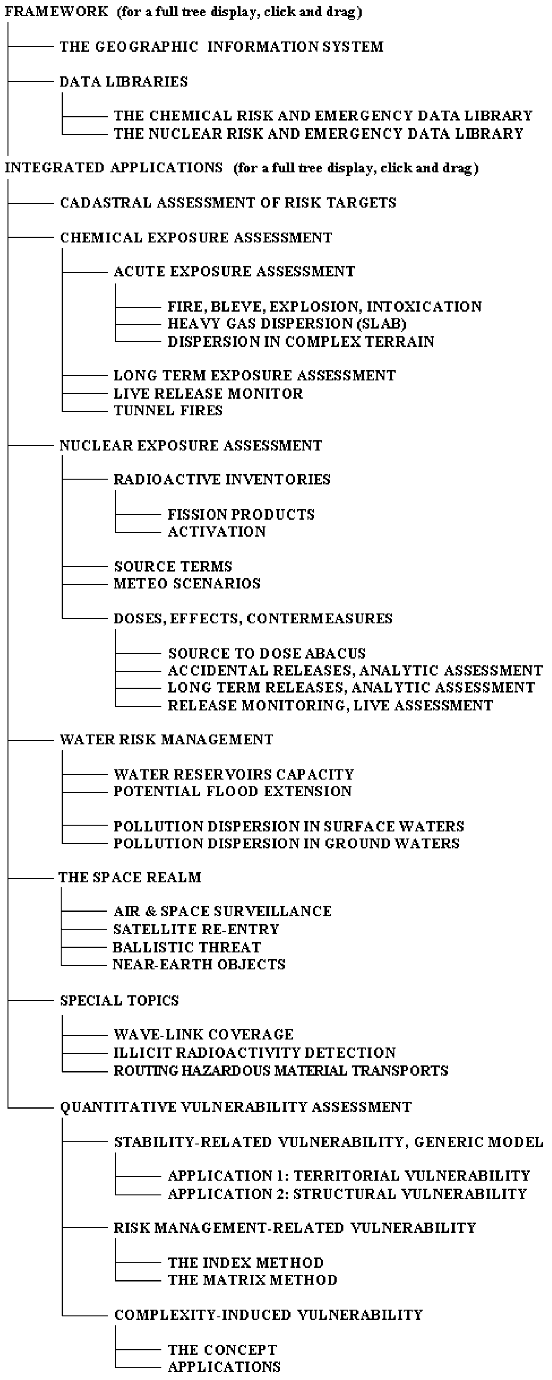
2.2. A working example

In one case, the aim of the DSS for electronic risks maps was to portray, and calculate risk related figures in order to communicate risk results or to use information existing in GIS and data libraries for calculating impacts of potential chemical- or nuclear accidents. The structure of the DSS included a chemical, and a nuclear database. The application software associates consequence models in order to implement chemical and nuclear accident consequence assessment and cadastral procedures to evaluate the impact of routine operation of chemical and nuclear installations, yielding in output affected area maps, together with—where feasible—rough statistics on the type of land use and population affected.

The following coverage of the problems was ensured, via specific modules:

2.2.1. Long-term exposure from routine chemical releases

Based on data on chemicals and the meteorology of a site, this module determines the areas where continuous releases to the atmosphere of hazardous chemicals pose health risks to individuals and to the public. Toxicity threats include concentration thresholds exceeding *the Immediately Dangerous for Life and Health* (IDLH), the *Threshold Limit Value* (TLV), the *Short Term Exposure Limit*, as well as *Expected Lethality Percentage*. As such, the module applies to normal releases, or protracted accidental releases relating to e.g. pipe breaks, or slowly evaporating spills. When working on



long-term meteorological statistics, the module may provide cadastral type of chemical risk information—a feature consolidated by code's capability of generating, together with the work-maps visualising the effect areas, statistics including data on exposed population, and land that draw upon the GIS framework. The code is designed to primarily handle buoyant or neutral gases [5].

2.2.2. Chemical accident consequence assessment

Based on data on chemicals and the meteorology at the time of an accidental release of hazardous chemicals to the atmosphere, this module determines areas of effect manifestation, such as fireballs, various kinds of explosion damage, and toxicity threats including lethality. The results may be GIS-linked for map overlaying. One feature of the code is that, together with the work-maps visualising the effect areas, statistics including data on the exposed population and land are also provided. Designed as a first-reaction tool, this facility targets fast, conservative evaluations thus assuming only a simple, severe scenario: the entire release is supposed to go out in a single puff, and straight downwind. Terrain is treated by the selection of an appropriate variety of dispersion parameters according to roughness. The code is designed to primarily handle buoyant or neutral gases.

2.2.3. Long-term exposure from routine nuclear releases

This is a health and environmental impact assessment tool. Based on data on fission products and other nuclides and the meteorology of a site, it determines the areas where continuous releases to the atmosphere of radioactive airborne pollutants pose health risks. Radiation doses from exposure to radioactive cloud passages and groundshine are computed, on a variety of pathways leading to external and internal irradiation. As such, the module applies to normal releases, or protracted accidental releases relating to e.g. isolation failure of plant containments holding active gases and aerosols. When working on long-term meteorological statistics, the module may provide cadastral type of nuclear risk information—a feature consolidated by code's capability of generating, together with the work-maps visualising the effect areas, statistics including data on exposed population, and land that draw upon the GIS framework.

2.2.4. Nuclear accident consequence assessment

This module implements model-derived computational *rules* to predict external and internal radiation doses that can be acquired following exposure to radioactive cloud passages and deposition, consecutive to accidental releases from nuclear installations. The rules are compiled in the U.S. Nuclear Regulatory Commission's series of 'RTM—Response Technical Manuals', including the 'RTM-95 International Response Technical Manual' that considers norms, procedures and practices agreed upon by the International Atomic Energy Agency (IAEA). Starting on (i) activity inventory summary evaluations, (ii) source term diagnoses based on plant status, and (iii) meteorological scenarios, that all can be performed online at the user's interface, the code (a) computes *dose-to-distance* functions, and scans work maps at pixel level, for dose situation; and (b) identifies *isodose* and related curves and overlays results onto event's work map. All computed quantities can be compared with a variety of health-effect and intervention-related normative-levels to assist emergency management.

As already indicated, the applications are I/O-connected to the code's resident databases, and GIS. The respective facilities are managed by appropriate engines.

Thus, CHEMDATA is user's interface to the variety of data in the code libraries that are required in chemical risk assessment operations. Essentially, the code gives access to 26 features, both quantitative and qualitative, for a default collection of substances totaling more than 700 entries. The initial variety of substances can be user-enhanced, and all data can be user-updated at any time. The module also accesses a pertinent knowledge base, at hand to recall basic model assumptions and the 'rules' and equations involved.

NUKEDATA brings about a comprehensive collection of data compiled from authoritative sources (U.S.NRC, EPA, DOE, IAEA) of relevance in the assessment of nuclear risks, and associated accident consequences. The data cover 155 fission product nuclides, 47 features of these, and a variety of supportive physical and procedural information. NUKEDATA serves the code's radiological assessment module.

2.2.5. Maps and GIS

Fig. 1 indicates a few uses of various types of maps in delineating relevant information for risk assessment and management, including the electricity generation activities.

The GIS information is held (i) in digital rasters of a variety of origins (e.g. U.S. Geological Survey, Swiss Federal Office of Topography); and (ii) in digital rasters derived online by the interpretation of image-map, including and especially aerial ortophotography and satellite imagery. The GIS routines interpolate data at pixel level, allowing, inter alia, (a) a mouse-driven scanning for GIS data, of maps in display, and (b) getting cadastral statistics of overall maps, of user-defined areas, or of areas marked for risk significance (impact quantities, countermeasure areas, etc.). The GIS-imaging engine features 3D viewing and animation capabilities (v. Fig. 2), based on *Open GL* and *MS Direct 3D* technology. Codes' capability to convert image maps of almost any origin and format to 'intelligent maps' fit for risk analysis and/or emergency planning/training/response purposes was found particularly valuable.

2.2.6. The assessment machine

2.2.6.1. Long-term assessment of chemical releases.

The environmental and health risk burden brought about by the electricity generation comes over a preexistent burden posed by the current industrial, transport and other activities in the targeted areas. A fair description of what electricity implies would therefore require a parallel assessment of e.g. potential health impacts from the chemical plants in operation. The code offers for demonstration computational facilities of the kind. Illustrative examples follow. The 3 ppm concentration area around a virtual ammonia plant, the local (virtual) annual meteorological statistics taken as reference is presented in Fig. 3. The inputs employed, that all are generated at the code's user interface, are illustrated in the sequel.

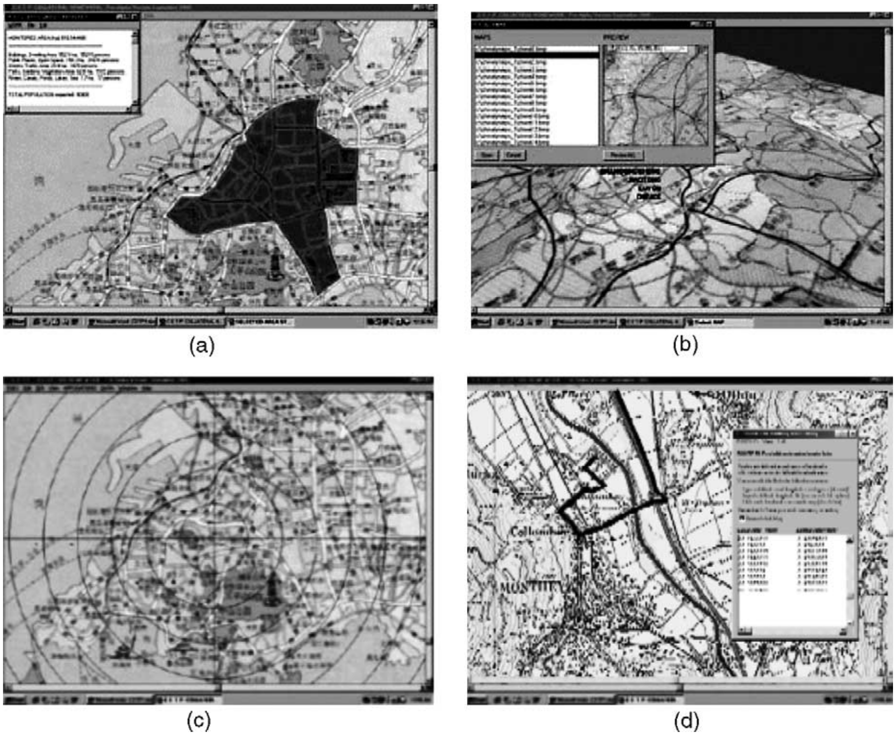


Fig. 1. Statistics of population and land use (a), of an user-defined polygonal area on a map selection (b), mapping risk areas (c), and routing hazardous cargos (d).

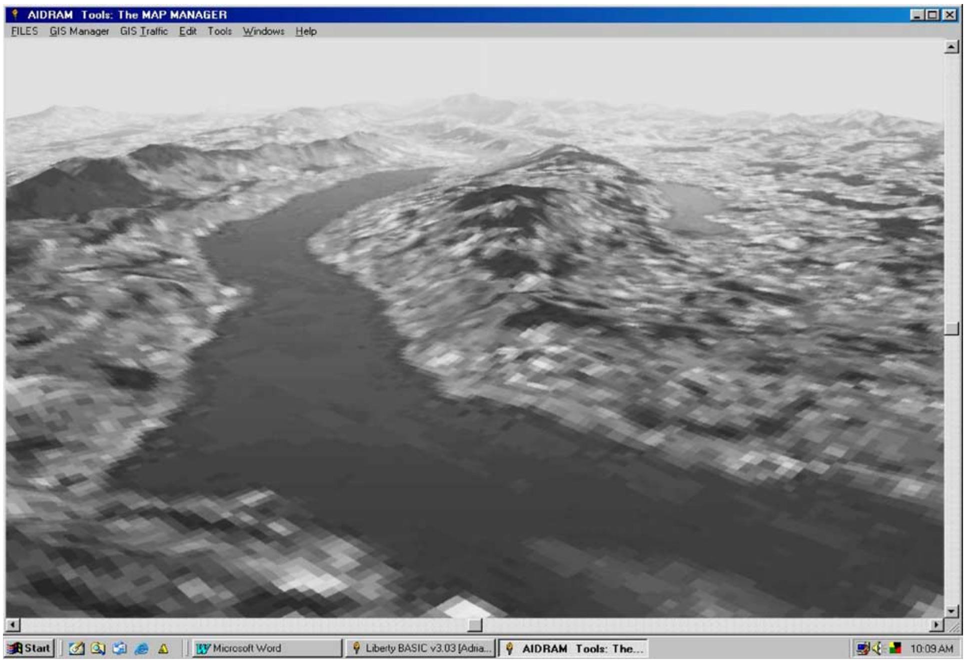


Fig. 2. A 3D view of Lake Zurich and landscape. Satellite picture, plus elevation raster.

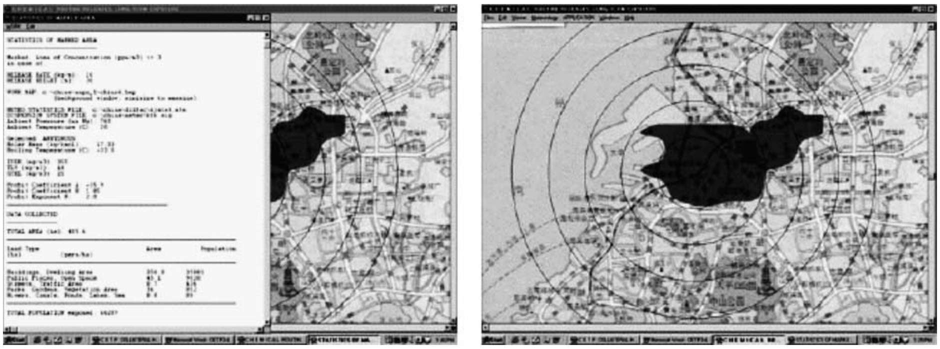


Fig. 3. Mapping impact areas of significant risk from long-term chemical releases.

Fig. 4. Areas of significant risk from a short-term (accidental) chemical release.

The associated file reads (selectively):

INPUT FILE

RELEASE RATE (kg/s): 10.0; RELEASE HEIGHT (m): 30.0
METEO STATISTICS FILE: c:\china\dilfac\kjstat.mts
DISPERSION SYSTEM FILE: Ambient Pressure (mm Hg): 760; Ambient Temperature (C): 20

Selected: AMMONIA ANHYDROUS
Molar Mass (kg/kmol): 17.03; Boiling Temperature (C): −33.0
IDLH (mg/m3): 355; TLV (mg/m3): 18; STEL (mg/m3): 25
Probit Coefficient A: −35.9; Probit Coefficient B: 1.85; Probit Exponent N: 2.0

3-D METEOROLOGICAL STATISTICS, pIJK, of Dispersal Conditions
Spanning a Wind Rose: 1–16 sectors of impact I
Diffusion Categories: 1–6 (F-A) J
Wind Velocity Categories: 1–30 K

2.2.7. *Chemical accident assessment (short release)*

The Immediately Dangerous for Life and Health (IDLH) risk indicator, and its area of exposure is represented for the case of a chemical accident (Fig. 4).

The respective Statistics File reads:

Accident Summary:

Subject-Chemical: AMMONIA ANHYDROUS
Mass involved (kg): 20000
Wind Speed (m/s): 3.5
Wind blowing from: 300 deg., N by E

Total Area (ha): 136.4

Land Type	Area (ha)	Population (persons)
Buildings, Dwelling Area	83.6	8366
Public Places, Open Space	6.2	5252
Streets, Traffic Area	18	902
Parks, Gardens, Vegetation Area	6.5	163
Rivers, Canals, Ponds, Lakes, Sea	1.9	19

TOTAL POPULATION exposed: 14702

The Consequence Assessment File serving the results above is given below and indicates the type of information needed by the code in order to perform its tasks for risk representation. The file reads:

CONSEQUENCE ASSESSMENT FILE

The code applies to rough evaluations of the extension of areas affected by fireball, explosion, and toxic effects of atmospheric releases of flammable/explosive/toxic GAS. Only chemicals that are in gaseous state at the ambient temperature can be approached. Given the ambient temperature, the code provides a list of the candidate-subject chemicals in its database.

I. TARGETED SUBSTANCE: AMMONIA ANHYDROUS

CHEMICAL AMMONIA ANHYDROUS
FORMULA NH3
MOLECULAR MASS (kg/kmol) 17.03
BOILING POINT (deg C) −33.0
FLASH POINT (deg C) NA
LATENT HEAT vapours (kJ/kg) 1370.0
SPECIFIC HEAT liquid (kJ/kg/K) 4.6
ISENTROPIC EXPONENT (Cp/Cv vapours) 1.31
SOLUBILITY (g/100 ml) 89.9
SPECIFIC GRAVITY (relative to water 4 C) .62
VAPOUR PRESSURE (mm Hg at 20 C) 7600
VAPOUR DENSITY (relative to air 0 C) .6
Van der Waals INTERNAL PRESSURE a (dyn.cm4) NA
Van der Waals COVOLUME (cm3/mol) NA
Critical PRESSURE (standard Atm) NA
Critical VOLUME (cm3) NA
Critical TEMPERATURE (C) NA
IDLH (mg/m3) 355
TLV (mg/m3) 18
STEL (mg/m3) 25
PROBIT FUNCTION coefficient a −35.9
PROBIT FUNCTION coefficient b 1.85
PROBIT FUNCTION exponent n 2.0
AUTOIGNITION TEMPERATURE (deg C) 630
EXPLOSION LIMITS (%V/V air) 45–128
COMBUSTION HEAT (J/kg) 1.848e7
FIRE HAZARDS:
- Combustible.
- Presence of oil or other combustibles increases fire hazard.

SYNONYMS: ammonia anhydrous; liquid ammonia

MASS of AMMONIA ANHYDROUS at release risk (kg): 20000

II. ENVIRONMENTAL INPUTS; To evaluate toxicity-related effects, the code needs to employ weather data. Such data are stored in 'meteo files', generated with KOVERS module METEO.

CONSEQUENT CODE OUTPUTS:
13. Atmospheric Stability Class: C
14. Inversion lid height: 800
15. Wind Power Law (vertical shear) exponent: 0.2000000
16. Average Temperature Gradient (K/m): −0.0160000
Calculation Wind Speed (m/s): 2.7510108; Power-Law-corrected for Height = 3.0

III. RISK RADII
Risk radii are determined for fireball and explosion damage - if the chemical is on record as flammable; and for all toxicity limits available, i.e. the IDLH, TLV, and STEL.
A. FIREBALL Radius resulting from 20000 kg of AMMONIA ANHYDROUS according to reference literature
Exercise expert judgment in order to select double-click line start, or depress left button and brush over)

Fireball Diameter (m)	Fireball Duration (s)	Source
91.8156902	7.13593447	[1]
61.4142066	4.86984898	[2]
148.800941	10.2807923	[3]
82.0387872	2.86073211	[4]
147.448205	1.58100047	[5]
158.961468	13.4339935	[5]

1/ High R.W. (1968). The Saturn Fireball. Annals of the New York Academy of Science, 152, 441–451.
2/ Brasie W.C. (1976). The Hazard Potential of Chemicals, AIChE Loss Prevention, 10, 135–140.
3/ Marshall V.C.(1977). Chemical Conturbations; The Domino Danger; Eurochem Conference Papers.
4/ Hasegawa K., Soto K. (1977). Study on the Fireball Following Steam Explosion of n-Pentane. 2nd Int. Symp. on Loss Prevention and Safety Promotion.
5/ Raj P.K. (1977). Calculation of Thermal Radiation Hazards from LNG Fires; A Review of the State of the Art. AGA Transmission Conference T135–148
6/ Hardee H.C., Lee D.O., Benedick W.B.(1978). Combustion Science and Technology, 17, 189–197.
User-selected FIREBALL Radius Approach, cf. The table above:

Fireball Diameter (m)	Fireball Duration (s)	Source
158.961468	13.4339935	[5]

B. EXPLOSION DAMAGE Circle Radius resulting from 20000 kg of AMMONIA ANHYDROUS

Yield Factor (%) assumed: .1
Combustion Heat (J/kg): 1.848e7
> Provide AMMONIA ANHYDROUS combustion heat, if not available (NA).
> Feel free to change numerical defaults, if appropriate.

Characteristic Damage Damage Factor
11. Heavy damage to buildings & processing equipment .03
12. Repairable damage to bldgs. and dwelling facades .06
13. Glass damage causing injury .15
14. Glass damage, ca. 10% of panes .40

Resulting Radii:

Characteristic Damage Radius (m)
11. Heavy damage to buildings & processing equipment 99.9306185
12. Repairable damage to bldgs. and dwelling facades 199.861237
13. Glass damage causing injury 499.653093
14. Glass damage, ca. 10% of panes 1332.40825

C. TOXIC RISK RADII resulting from 20000 kg of AMMONIA ANHYDROUS
MAXIMUM RISK RADIUS (m) based on STEL = 3067.27929; TIME (s) of STEL risk persistence = 1090

RISK RADII Summary

Risk	Category	Radius (m)	Duration (s)
C01.	Fireball Exposure	79.480734	13.4339935
C02.	Explosion-Induced Heavy Damage to Buildings and Processing Equipment	99.9306185	NA
C03.	Explosion-Induced Repairable Damage to Buildings and Dwelling Facades	199.861237	NA
C04.	Explosion-Induced Glass Damage causing injury	499.653093	NA
C05.	Explosion-Induced Glass damage, affecting ca. 10% of panes	1332.40825	NA
C06.	Toxic Exposure based on IDLH	2665.96227	946
C07.	Toxic Exposure based on TLV	3498.35293	1245
C08.	Toxic Exposure based on STEL	3067.27929	1090

NA - Not Applicable

LETHALITY AND TOXIC DOSES
for 6 min. exposure to AMMONIA ANHYDROUS under current atmospheric conditions ($P = 755$ mm Hg, $T = 20.000000\,^{\circ}$C)
From Toxicity Probit Function data, the code infers the Toxic Doses, i.e. the Time-Integrated Power-Concentrations over the input exposure time corresponding to different expected lethality percentages, and then scan distances downwind from source to determine the radii of the areas within which the respective condition holds.

Lethality Probit TOXIC DOSE LETHALITY

	Percentage (%)	Time-Integrated (ppm$\hat{2}$.min)	Nth-Power Con.	RADIUS (m)
C09.	1%	1.475	5.94185847e8	206.32581
C10.	5%	3.35	1.63713928e9	162.309637
C11.	10%	3.72	1.99960644e9	154.056605
C12.	20%	4.16	2.53650771e9	145.803572
C13.	30%	4.48	3.01548654e9	140.301551
C14.	40%	4.75	3.48932091e9	137.55054
C15.	50%	5	3.99419586e9	132.048518
C16.	60%	5.25	4.57212189e9	129.297508
C17.	70%	5.52	5.29055604e9	123.795486
C18.	80%	5.84	6.28959276e9	118.293464
C19.	90%	6.28	7.97837026e9	112.791443
C20.	99.8%	7.88	1.89461175e10	90.7833564

2.2.8. Long duration nuclear releases

Contemplating the nuclear alternative for power generation goes along with potential health risks that should also be accounted for. In the same line, any newly-added, planned chemical industrial facility would also add to the risk. Such risks may be termed ‘background risks’, and be accounted for much in the same manner that the background radiation doses—particularly in territories of high levels (radon, mine tilings, etc.)—are taken into consideration in radiological assessments.

Longer-term nuclear releases, originating either in the routine power plant, and fuel cycle plant operations, or in protracted releases to environment following originally contained in-plant accidental releases, make also a case for risk mapping. An example bearing on a potentially severe, protracted release of 10 Ci/s over 7 days, from a 1000 MWe, LWR nuclear power unit is given in Fig. 5. The p*opulation sheltering area*, recommended for a total effective dose equivalent (TEDE) ≥ 1000mrem (IAEA) is shown in Fig. 5a. The *population evacuation area*, recommended for (TEDE) ≥ 5000mrem (IAEA) is indicated in the magnified *b*-section of the figure.

2.2.9. Nuclear accident assessment

A virtual CANDU 700 MWe unit bypass accident is considered. Release is set at ca. 6.13 MCi, i.e. the same total as with the LWR long term release in the preceding section, yet with a different, specific isotopic mix.

The calculation indicates a series of risk related indicators which could be of use in case of emergency planning and management. The risk mapping outline of the information is for direct communication with stakeholders in case of accidental situations. The results are easily converted in a series of actions which could involve specific emergency activities such as relocation, sheltering, etc. of people and lifestock [7].

Doses as functions of distance from source are sketchily documented in the sequel. The code parallels such listings with health effect and countermeasure-related normative levels, in order to assist decision on sheltering, evacuation, iodine administration, relocation, food bans, population screening, decontamination, etc., as appropriate *several essential inputs* are retained in the list header. Results of an interactive scanning of the map field are shown in Figs. 6 and 7.

DOSE-to-DISTANCE relationship at 0 deg. from wind

DIRECT SOURCE TERM.
Effective ESCAPE DURATION (minutes): 60
Atmospheric stability category: B + 0.9019525 C
Average wind speed (m/s): 3.29824561
Standard deviation of wind direction (deg): 15.4902377
Release type: Ground
Precipitations: No Rain
Cloud exposure duration (h): 4
Ground exposure duration (h): 168
External Shielding Factor: 1
Inhalation Shielding Factor: 1

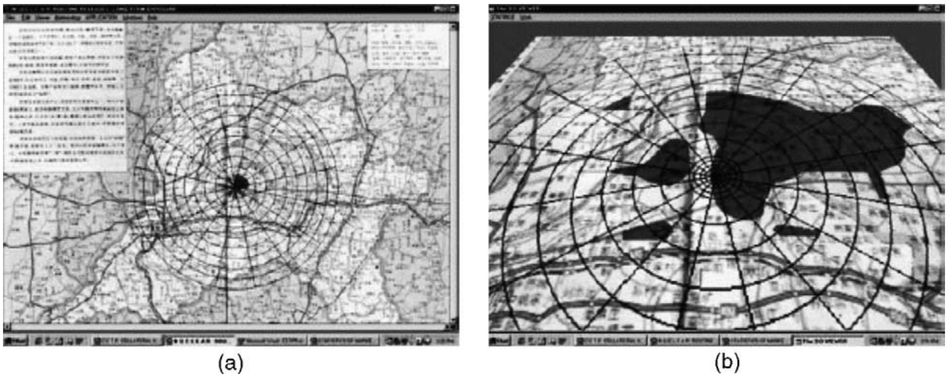
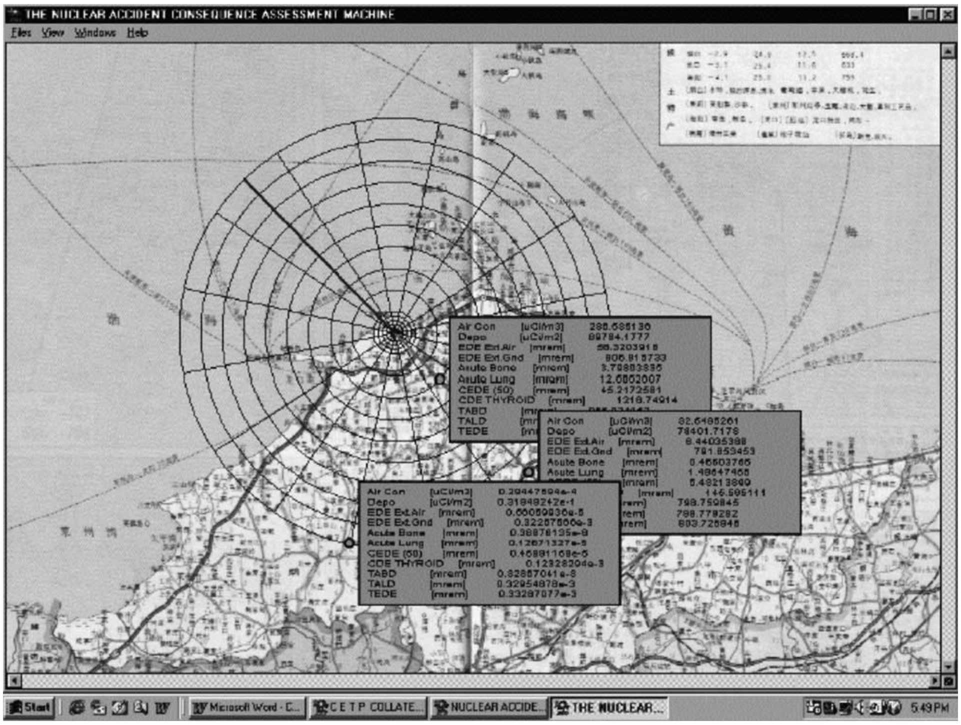


Fig. 5. Mapping areas of significant risk from long-term radioactive releases.



```
Air Con          [uCi/m3]      288.685130
Depo             [uCi/m2]      89784.1777
EDE Ext.Air      [mrem]        58.3203918
EDE Ext.Gnd      [mrem]        806.815733
Acute Bone       [mrem]        3.70883836
Acute Lung       [mrem]        12.0802007
CEDE (50)        [mrem]        45.2172581
CDE THYROID      [mrem]        1218.74914
TABD             [mr
TALD             [mr
TEDE             [m
```

```
Air Con          [uCi/m3]      32.6485261
Depo             [uCi/m2]      78401.7178
EDE Ext.Air      [mrem]        8.44035388
EDE Ext.Gnd      [mrem]        791.859453
Acute Bone       [mrem]        0.46603766
Acute Lung       [mrem]        1.48647468
                 [mrem]        5.48213849
                 [mrem]        146.595111
                 rem]          798.759845
                 rem]          798.779282
                 rem]          803.728848
```

```
Air Con          [uCi/m3]      0.29447594e-4
Depo             [uCi/m2]      0.31849242e-1
EDE Ext.Air      [mrem]        0.66059930e-5
EDE Ext.Gnd      [mrem]        0.32267660e-3
Acute Bone       [mrem]        0.38878195e-8
Acute Lung       [mrem]        0.12671327e-5
CEDE (50)        [mrem]        0.46881168e-5
CDE THYROID      [mrem]        0.12328204e-3
TABD             [mrem]        0.82887041e-8
TALD             [mrem]        0.32954878e-3
TEDE             [mrem]        0.33287077e-3
```

Fig. 6. Selective results of interactively scanning the map field.

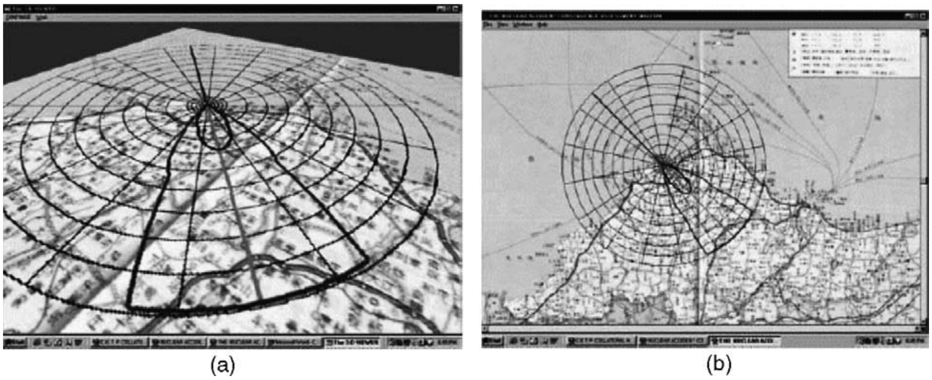


Fig. 7. The Sheltering (a) 1000 mrem in 7d, IAEA and Evacuation (b) 5000 mrem, IAEA zones for a ca. 6 MCi CANDU-700 Containment Bypass Accident

Distance km	Air Con [uCi/m3]	Depo [uCi/m2]	EDE Ext. Air [mrem]	EDE Ext.Gnd [mrem]
1	24918.4694	924026.746	4893.57896	9332.62421
2	7205.97551	587930.908	1415.33639	5938.07295
3	3470.32779	424616.825	681.700876	4288.60882
4	2064.8438	356022.026	405.676535	3595.80477
5	1380.03763	311111.824	271.179603	3142.21396
6	1182.91533	266201.622	232.444459	2688.62315
7	985.823091	221291.419	193.71522	2235.03234
8	788.730854	176381.217	154.98598	1781.44153
9	591.638618	164129.758	116.277199	1657.7024
10	394.546381	151881.521	77.5684201	1533.99582

The CANDU Source Term taking into account only some contributing nuclides, out of 155 nuclides in the code's libraries, is also listed:

SOURCE TERM Characterization:
DIRECT SOURCE TERM: Containment Bypass Accident
Effective ESCAPE DURATION (minutes): 60

TOTAL ACTIVITY RELEASED, per isotope [Ci]:
H-3 5189189.1
Kr-88 4594594.5
I-131 78378.376
I-132 111891.89
I-133 143783.76
I-134 161891.89
I-135 126486.47
Xe-133 15054054
Xe-135 2540540.5

TOTAL ACTIVITY RELEASED
(all isotopes, [Ci]): 28000810.5
Fraction adopted: 0.21893434, i.e. ca 6130339 Ci

Source terms are obtained following the procedure recommended in the U.S. Nuclear Regulatory Commission's *Response Technical Manual* series (v. [2–4]). The computation considers: the reactor inventory corrected for the time since shutdown; the core release fractions for nuclides; the escape fractions depending on the accident scenario; the assumed core temperature increment rate induced by the loss of coolant; the time of core-uncovered; and the time of effective escape of gases and aerosols to atmosphere—also scenario-dependent.

The Meteo Scenario, shared by the CANDU and LWR cases is rendered in the following table.

METEO FILE: C:\CHINA\NOTEPAD\METEO\C_G_NR.MET
Dispersion System: Karlsruhe-Julich

Atmospheric Stability Class	B + 0.9019525 C
Cloudiness Fraction	0.46370968
Average Wind Speed [m/s]	3.29824561
Average Wind Direction [deg]	315.725219
Wind Direction Standard Deviation [deg]	15.4902377
Release Level	Ground
Precipitations	No Rain

DILUTION FACTORS

0 [km]	0.35188815e-4 [1/m2]
0.5 [km]	0.35188815e-4 [1/m2]
1 [km]	0.10566624e-4 [1/m2]
2 [km]	0.3055984e-5 [1/m2]
3 [km]	0.14717628e-5 [1/m2]
4 [km]	0.87570381e-6 [1/m2]
5 [km]	0.58527808e-6 [1/m2]
10 [km]	0.16732311e-6 [1/m2]
25 [km]	0.31960203e-7 [1/m2]
50 [km]	0.91373206e-8 [1/m2]

DEPOSITION FACTORS

0.5 [km]	3.9e-8 [(kBq/m2)/kBq]
2.0 [km]	2.1e-8 [(kBq/m2)/kBq]
3.2 [km]	1.4e-8 [(kBq/m2)/kBq]
8.0 [km]	6.3e-9 [(kBq/m2)/kBq]
16.0 [km]	2.8e-9 [(kBq/m2)/kBq]

The meteorological scenario interface involves (a) the selection of an appropriate *system of dispersion coefficients* (Karlsruhe-Julich, Brookhaven, St. Louis, TNO, etc.) in consideration of the terrain roughness; and (b) setting wind direction, wind speed, cloud cover fraction, precipitations, and source elevation. The atmospheric stability class follows from the combination wind speed–cloudiness, also in consideration of the season (spring, summer, fall, winter), and time of the day (daytime, night-time).

3. Conclusion

The paper illustrates a manner of risk assessment and communication that shows the following features:

- Aims at preventive, and/or response, *decisions*.
- Focuses on *hazards*, measured by expected consequences of disruptive abnormalities.
- Uses *rules* implying *representative data* to assess consequences, thus (i) integrating a necessary statistical dimension; (ii) ensuring both technical soundness and legal acceptability, and (ii) improving chances of risk communication.
- Maps the results—that are expressed whenever feasible in lives/health potentially affected, and money—in space and time, thus further favoring a decision-oriented risk perception.

In particular, an experiment is presented, on the use of risk maps as instruments to accommodate results from risk calculations relating to chemical or nuclear industry operations, and a comprehensive use of GIS technology for risk representation and communication. Most of the examples were derived from a co-operative exercise having the electricity generation strategies in China as target (v. e.g. [8]).

The development of decision support systems for assessing risks due to electricity generation as well as for comparative risk assessment of various generation technologies is becoming a standard, and compelling approach. It is also an appreciated aid in preparing for emergency situations and in addressing health, environmental, and operational aspects of such diverse activities like the land use planning; resource management; life-cycle issues such as the decommissioning of nuclear power plants and fuel cycle facilities; transportation of hazardous materials; the management of wide-scale, spatially distributed businesses; and the vulnerability of critical infrastructures.

References

[1] J. Nilsson, S.E. Magnusson, P.O. Hallin, B. Lenntrop, Model for Vulnerability Auditing and Distribution of Governmental Economic Means at the Local Authority Level, Lund University, 2002.

[2] Th.J. McKenna, J.A. Trefethen, Zhiguang Li, International RTM-95 Response Technical Manual, U.S. Nuclear Regulatory Commission, IRD/AEOD, May 1995.

[3] Th.J. McKenna, K. Jackson, J. Trefethen, R. Bores, R. Struckmeyer, G. Kuzo, R. Hogan, J. Jolicoeur, J. Quissell, K. Gant, B. Burnett, O. Aguillar-Torres, G. Athey, L. Grove, R. Hopkins, The RTM Response Technical Manual, U.S. Nuclear Regulatory Commission, DOA/AEOD, 1993.

[4] Th.J. McKenna, J. Trefethen et al., FRMAC Assessment Manual—The Federal Manual for Assessing Environmental Data during a Radiological Emergency, U.S. NRC/DOE/EPA, July 1995.

[5] The American Institute of Chemical Engineers, Guidelines for Chemical Process Quantitative Risk Analysis, AIChE Center for Chemical Process Safety, ISBN-8169-0402-2, 1989.

[6] A. Gheorghe et al., Integrated Risk Assessment and Safety Management Transportation of Dangerous Goods, Int. J. Risk Assess. Manage. 3 (2–4) (2002) 99–112.

[7] D. Vamanu, G. Mateescu, A. Berinde, D. Slavnicu, V. Acasandrei, A Code Comparison Exercise within the European Project RODOS: Harmonizing Domestic and Reference Tools, Int. J. Risk Assess. Manage. 3 (2–4) 2002.

[8] B. Eliasson, Yam Y. Lee (Eds.), Integrated Assessment of Sustainable Energy Systems in China, Kluwer Academic Publishers, Dordrecht, 2003.