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UTILIZATION OF DOSE ASSESSMENT MODELS TO FACILITATE OFF-SITE RECOVERY OPERATIONS FOR ACCIDENTS AT NUCLEAR FACILITIES

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Utilization of Dose Assessment Models to Facilitate Off-Site Recovery Operations for Accidents at Nuclear Facilities

ABSTRACT

One of the most important uses of dose assessment models in response to accidents at nuclear facilities is to help provide guidance to emergency response managers for identifying, and mitigating, the consequences of an accident once the accident has been terminated. By combining results from assessment models with radiological measurements, a qualitative methodology can be developed to aid emergency response managers in determining the total dose received by the population and to minimize future doses through the use of mitigation procedures. To illustrate the methodology, this discussion focuses on the use of models to estimate the dose delivered to the public both during and after a nuclear accident.

A three-dimensional, mass conservative, diagnostic wind field model coupled to a particle-in-cell diffusion code is used to simulate the radiological effects from a hypothetical nuclear power plant accident. Although the power plant used in this simulation is hypothetical, the meteorological and topographical input to the models was taken from real-world measurements for a particular location in the northwestern United States. Because these models are three-dimensional, however, they can be generalized for application to different sites without tailoring for each unique location. Although these models can be used for operational real-time calculations, this discussion will emphasize their post-accident assessment use.

Results of the calculations for this paper are displayed in graphical form to show the area impacted by the accident as it pertains to various doses and potential doses received by the public within about 100 kilometers of the plant site. Radiological effects from three selected nuclides (I-131, Cs-137, and Xe-133) are modelled for demonstration purposes. The information depicted in these calculations can then be used to help determine any additional mitigation measures that need to be implemented. Examples of the use of these calculations by the emergency response manager to better manage available resources are also described in this paper.

1. Introduction

One of the most important questions asked after a nuclear accident is, "what dose has been delivered to the public?". In most cases it is important to identify dose by the different pathways and also by total dose received during the accident. In addition, officials want to know the dose delivered to the public from living in a contaminated area so that decisions can be made regarding relocation and/or cleanup of the contamination.

To estimate the doses received by the public during an accident and the doses they will receive living in a contaminated area after the accident, both model calculations and environmental measurements are available to the emergency response manager. In an ideal sense these two resources should be combined in a quantitative fashion to provide these estimates; however, the technology to accomplish this task is in its infancy and is not yet available in an operational setting. Therefore, for purposes of this paper, the discussion will be focused on the use of models to estimate the dose delivered to the public both during and after a nuclear accident. Results from these calculations can be a valuable aid to help with the recovery operations. In order to keep the length of material in this paper reasonable only three radionuclides (I-131, Xe-133, and Cs-137) will be used in the calculations. Obviously, for an accident, all radionuclides that contribute to the dose should be included in the dose calculations.

For the dose calculations shown in this paper the MATHEW/ADPIC models[1,2], that are part of the US Department of Energy's Atmospheric Release Advisory Capability (ARAC)[3], have been used. These models are three-dimensional and include terrain explicitly. They are diagnostic, and therefore use measured wind speeds and directions, interpolated to a grid volume and adjusted to satisfy the mass continuity equation. Although the location and meteorological and topographical data are real, the reactor used in this study is not. In the last section we show a final estimate of the dose due to the Xe-133 that was released during the TMI-2 accident in 1979. Calculations shown in this example were used by the US President's Commission to help estimate the final dose to the public living around the reactor site. Finally, the intent of this paper is to show a methodology and not to explicitly describe effects or suggest protective actions.

2. The Problem

2.1. Description of the Terrain

Figure 1 shows a 200 × 200 km computer generated view of the terrain features around the hypothetical nuclear power plant site. The facility is assumed to be located in the center of the figure in an area that is relatively flat. To the southeast and the southwest of the facility there are valleys and ridges with terrain variations up to 1500 meters. Toward the northwest the terrain is relatively smooth with a valley oriented east-west along the southern edge of the quadrant. The northeast quarter varies from relatively smooth close to the facility to ridges and valleys away from the facility. In addition to influencing the wind flow patterns, these terrain features can and do influence the deposition patterns due to partial impacting of the airborne material as it moves over valleys and approaches ridges on the downwind side. This terrain data base was generated from a real data base and represents an area in the northwestern part of the US.

2.2. Description of the Geography

Figure 2 depicts the geographical features on a scale of 160 km surrounding the hypothetical nuclear power plant. This base map will be used for overlaying the contour patterns. Towns A and B represent the most populated areas of the region with populations of about 20,000 each. Much of the region is forested with most of the agricultural land lying to the northwest of the plant. The major national roads in the area are I-12, I-7, with the other roads such as S-222, S-216 and S-219 representing local road systems. Areas in the southeast, southwest and northeast do not have national or local roads due to the rugged terrain; however,. these areas would likely have farm roads and trails. The national roads are heavily traveled since they carry much of the truck and car traffic moving between states.

2.3. Accident Sequence

The methodology may best be illustrated by application to a simulated accident at a hypothetical nuclear power plant. The plant is a 1000 MWe pressurized water reactor that has been in operation for several years. The postulated accident under consideration is a small loss of coolant accident that leads to a failure of the emergency cooling injection system. This loss of coolant causes the core to be partly uncovered: a condition that subsequently leads to partial fuel melting. Radioactivity escapes from the core into the containment atmosphere and is partially removed by various mitigation systems, such as water sprays and filters, prior to release into the environment. On the basis of the inventory of radionuclides in the core, the expected fractional releases of various radionuclide transport groups for this particular accident sequence, the reduction due to the mitigation systems, combined with measurements (hypothetical) monitored by an on-site computer, derived source term estimates for this example are given in Table I.

2.4. Meteorological Conditions

Real meteorological conditions were used for these calculations. The data started at 1700Z, February 22, 1989 and ended 32 hours later when the final calculations were complete. At 1700Z, when the release starts, synoptic conditions show the accident area approximately equi-distant

Table I

Source Terms

	I-131	**Cs-137**	**Xe-133**
Amount Released in 6 hrs (Bq)	1.8×10^{17}	3.7×10^{14}	6.1×10^{18}
Source Rate (Bq/s)	8.3×10^{12}	1.7×10^{10}	2.8×10^{14}

from a surface high to the southeast and a surface low to the northwest. The cold front associated with the low is about 700 kilometers to the west. North-northeasterly flow is dominate in the release point area with a speed of 3 m/s at 020 degrees. During the time period 2000–2200Z, surface stations near the accident site report a shift from the north-easterly winds to more southeasterly (the surface wind field thus has a more northwesterly component). The release ends at 2300Z. Reports available from the site at that time show light (2 m/s) southerly winds. Surface winds remain easterly to the north of the release area. The station 120 kilometers to the northwest of the release area reports, at 0000Z February 23, 1989, a sudden wind shift to west-southwesterly at 5 m/s. The station 80 kilometers to the northwest of release area reports a similar wind shift, giving uniform westerly flow to the north of the accident point. Surface winds at the accident point shift to become southwesterly (240 at 5 m/s) as the surface trough passes over the area with the weakening cold front approximately 150 kilometers to the west. Conditions remain fairly constant through the night (0200Z–1200Z). During 1200Z–0000Z the surface high drifts slowly east-southeast setting up fairly uniform easterly surface flow over the entire area.

3. Results

Figure 3 shows the inhalation pathway 50 year committed adult thyroid dose for I-131. Within the largest contour value, which includes about 98 sq km, the thyroid dose to an unsheltered adult is greater than 1 Sv. In an area of about 672 sq km adults received a thyroid dose of between .1 and 1 Sv under the same conditions of no credit taken for shelter or evacuation.

Total I-131 deposition is shown in Figure 4. Potential dose to an adult drinking milk from cows grazing within the 1×10^7Bq/m^2 contour area (about 207 sq km) is approximately 15 Sv. Again this dose estimate assume no mitigation and is based on available I-131 on the ground immediately after the accident. With an 8 day half-life this estimate will be reduced within a relatively short period of time.

Figures 5 and 6 show the inhalation pathway effective whole body dose and deposition for Cs-137. The inhalation dose is about 2 orders of magnitude less than it is for I-131 ($.03 \times I - 131$ adult thyroid dose equals the inhalation effective whole body dose). The dose delivered through the cow-milk pathway due to deposition of Cs-137 is approximately 15 mSv, about 3 orders of magnitude less than it is for I-131. However, with an over 30 yr half-life, deposition of Cs-137 near the reactor site could pose a problem regarding land use. Figure 7 shows the Xe-133 effective whole body dose for the air immersion pathway. This dose is an order of magnitude less than the effective whole body dose received through I-131.

Figures 8 and 9 show combined effective whole body dose and dose rate for I-131, Xe-133 and Cs-137 inhalation and I-131 and Cs-137 deposition. The effective whole body dose (Figure 8) is largely given by I-131, with minor contributions from Xe-133 and Cs-137. Within the 10 mSv contour, the public over an area of about 300 sq km received doses greater than 10 mSv assuming no protective actions were taken. For dose from deposition (ground shine), figure 9 shows a dose rate over 10^{-5} mSv/s from I-131 and Cs-137 for an area of approximately 118 sq km. This dose rate translates to approximately 1 mSv/day immediately after the accident and then decays due to the 8 day half-life of I-131.

4. TMI-2 Accident Assessment

Although the TMI-2 accident in 1979 only released significant amounts of Xe-133 and therefore recovery operations for the environment around the reactor site were not necessary, model calculations were used to help estimate individual doses to the public and population doses to those persons living within about a 50 km radius of the reactor site. Figure 10 shows the integrated individual inhalation—immersion dose for a 10 day integration period delivered by the Xe-133 escaping from the TMI-2 reactor buildings. This dose estimate was used by the US President's Commission on TMI to estimate the dose received by the population. This 10 day integration used hourly measured windspeeds and directions from 5 locations. The maximum individual dose received form this calculation was 0.12 mSv. From this calculation, and including the population distribution around the reactor site, approximately 35 person-Sv were delivered to the population living in the calculational area during the accident. Since only Xe-133 was released the total dose calculation was considerably easier to estimate than had a suit of fission products escaped from the reactor.

5. Interpretation and Use

As the model calculations become refined in the post-accident environment, whether from the incorporation of radiological measurements or from fine tuning of model inputs based on the increased understanding of the accident scenario, a clear and concise conceptulization of the radiological effects should emerge. It is the presentation of this current level of understanding in a simple and easily interpreted manner which is of prime importance to the emergency response manager. Once confidence in the model simulation of a given event is established, detailed information may be extracted from graphical presentations of assessment calculations such as those shown above.

Typical uses of model simulations may be illustrated by referring to Figures 3 and 4, as an example. For instance, once model projections of I-131 deposition in selected areas are confirmed by measurement data, available resources for I-131 dose mitigation may be concentrated, not just in the area immediately adjacent to the accident source location, but also in the isolated areas indicated as potential hot spots by the model dose estimates (such as those indicated by the 100 mSv contours).

Although calculations may be generated for shorter integration periods, or even instantaneous points in time, the spread of the radiological effects as a function of time may be inferred from the dose and deposition patterns integrated for the entire accident period, as shown here. Knowledge of the surface wind history during the 32 hour integratoin period explains the tri-directional innermost contours of the dose calculations. These, of course, reflect the three dominate wind directions (to the Southwest, then Northwest, finally North) during the 32 hour period. However, careful interpretation of this would conclude that all areas in a clockwise arc from Southwest to Northeast of the accident site would have beeen exposed to the full concentration of the plume for shorter periods of time.

It would, therefore, be from the utilization of such dose assessment products, along with all other information available to the emergency response manager, that appropriate decisions could be made for allocation of proper resources and institution of mitigation efforts.

6. Summary

Discussions in this paper were designed to illustrate a methodology, using dose assessment models, that can be used to help authorities assess the effort of a nuclear accident on the public health and environment and provide them information that can be used during recovery operations. The example accident and three radionuclides used in this study were chosen to illustrate a general methodology.

The integration of model output and field measurements of airborne radioactivity, we believe, has an even greater potential of being a powerful tool for the authorities to use during recovery operations; however, as we discussed earlier, this work is in its infancy and has yet to be formulated for use in an operational environment. Recently (1989) considerable attention has been focused on developing and testing these tools (e.g., see Ref. 4) and we believe that in the near future operational tools will begin to emerge that will allow the combining of both the modeling and measurements to produce a more complete and accurate dose assessment.

7. Acknowledgement

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8. Figure Captions

Figure 1. Computer generated terrain view for a 200 km × 200 km area centered on the example reactor site.

Figure 2. Geographic map depicting roads and towns within a 160 km × 160 km area centered on the reactor site.

Figure 3. 50 yr committed adult thyroid dose due to the I-131 inhalation pathway (mSv).

Figure 4. I-131 deposition pattern (Bq/m^2)

Figure 5. Effective whole body dose due to the Cs-137 inhalation pathway (mSv/s)

Figure 6. C-137 deposition pattern (Bq/m^2)

Figure 7. Same as figure 5 except for Xe-133 air immersion dose (mSv)

Figure 8. Same as figure 5 except for the total dose from I-131, Xe-133 and Cs-137 (mSv)

Figure 9. Effective whole body ground exposure dose rate due to deposition of I-131 and Cs-137 (mSv)

Figure 10. Isopleths of integrated air concentration (mSv) for inhalation-immersion dose at 2-m elevation due to Xenon-133 released during the TMI-2 nuclear rector accident. (this plot represents 240-hr integration valid at 1200z, 7 April 1979; maximum calculated value is 0.12 mSv).

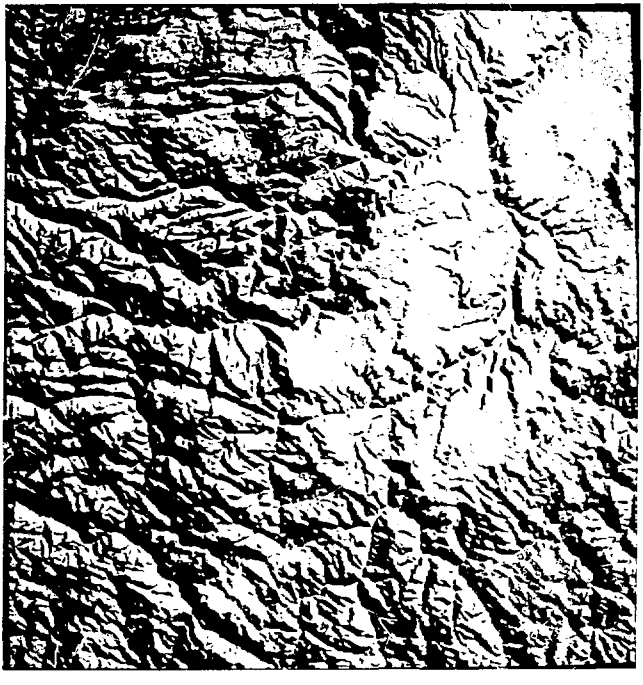
9. References

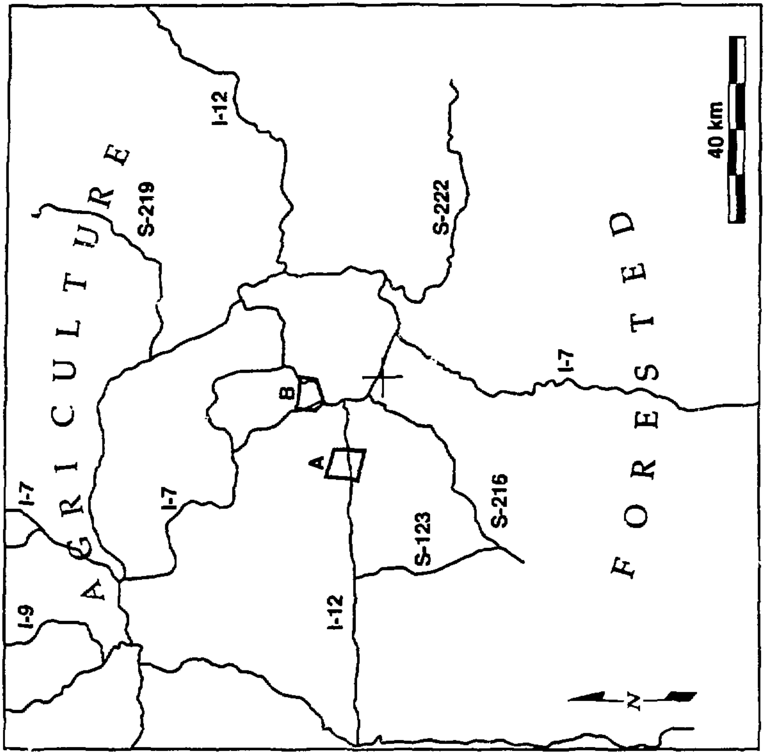
[1] SHERMAN, C. A., A Mass-Consistent Model for Wind Fields Over Complex Terrain, J. Appl. Meteor. 17 (1978) 312–319.

[2] LANGE, R., ADPIC-A Three Dimensional Particle-in-Cell Model for the Dispersal of Atmospheric Pollutants and its Comparison to Regional Tracer Studies, J. Appl. Meteor. 17 (1978) 320–329.

[3] DICKERSON, M. H., GUDIKSEN, P. H., SULLIVAN, T. J. and GREENLY, G. D., ARAC Status Report, Lawrence Livermore National Laboratory Report, UCRL-53461 (1985).

[4] EDWARDS, L. L., HARVEY, T. F. and PITOVRANOV, S. E., "Real-Time Regression Schemes for Integrating Measurements with Emergency Response Predictions", "Proceedings of the Second Workshop on Real-Time Computing of the Environmental Consequences of an Accident Release to the Atmosphere from a Nuclear Installation", "Decision Aids to Off-Site Emergency Response Management", Commission of European Communities, Luxembourg, May 16–19, (1989).

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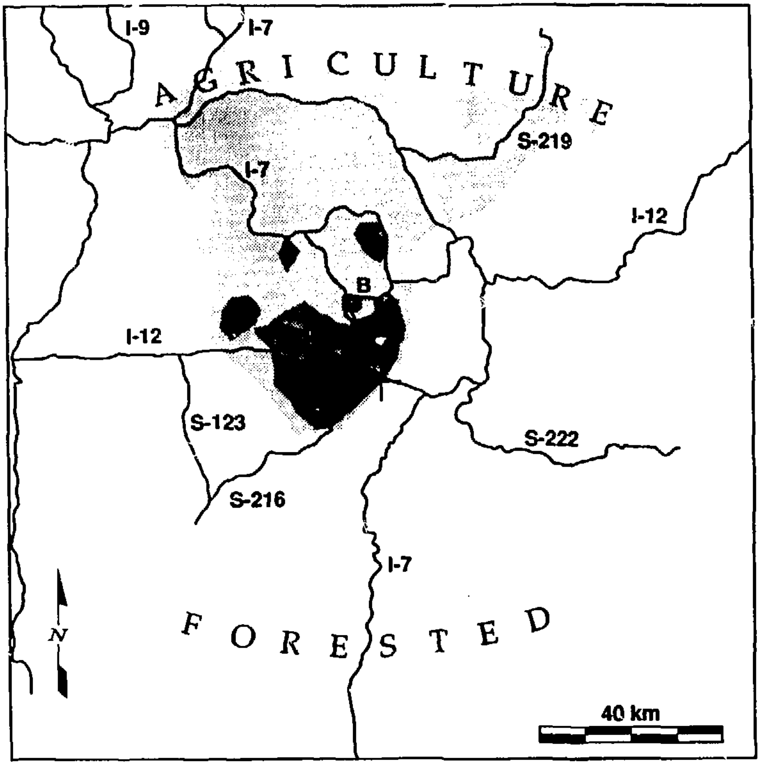


Remarks:

Inhalation pathway
50 year committed
adult thyroid dose

Integrated:

Feb. 22, 89 1700 Z
to Feb. 24, 89 0100 Z

Material:

I-131 at 1.5 m

Contour values
(in mSv)

■ > 10^3

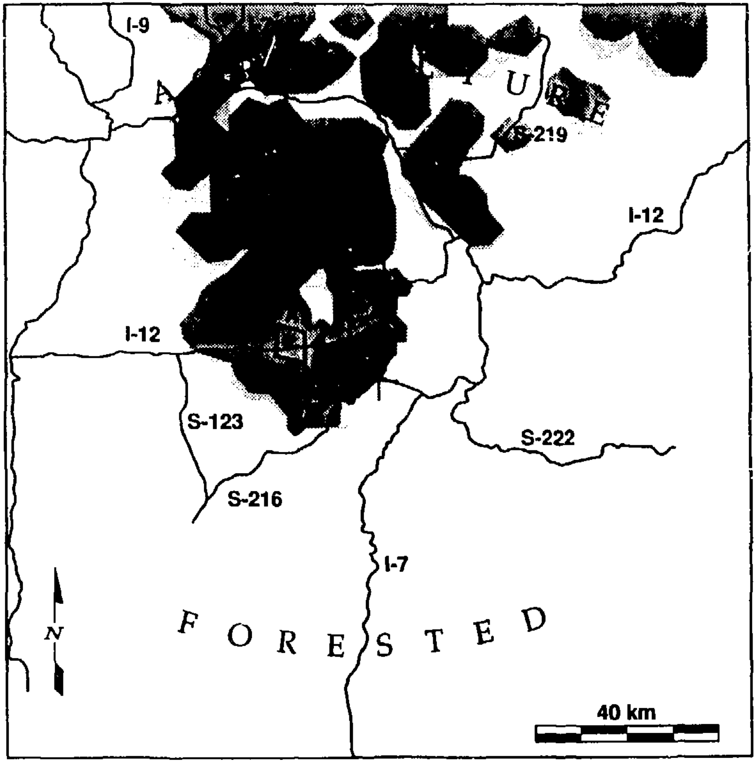
Area covers 98 sq. km.

▨ > 10^2

Area covers 672 sq. km.

░ > 10^1

Area covers 4927 sq. km.



Remarks:

Cumulative deposition

Integrated:
Feb. 22, 89 1700 Z
to Feb. 24, 89 0100 Z

Material:
I-131 at 0.0 m

Contour values (in Bq/m^2)

■ > 10^7
Area covers 207 sq. km.

▨ > 10^5
Area covers 3677 sq. km.

□ > 10^3
Area covers 4079 sq. km.

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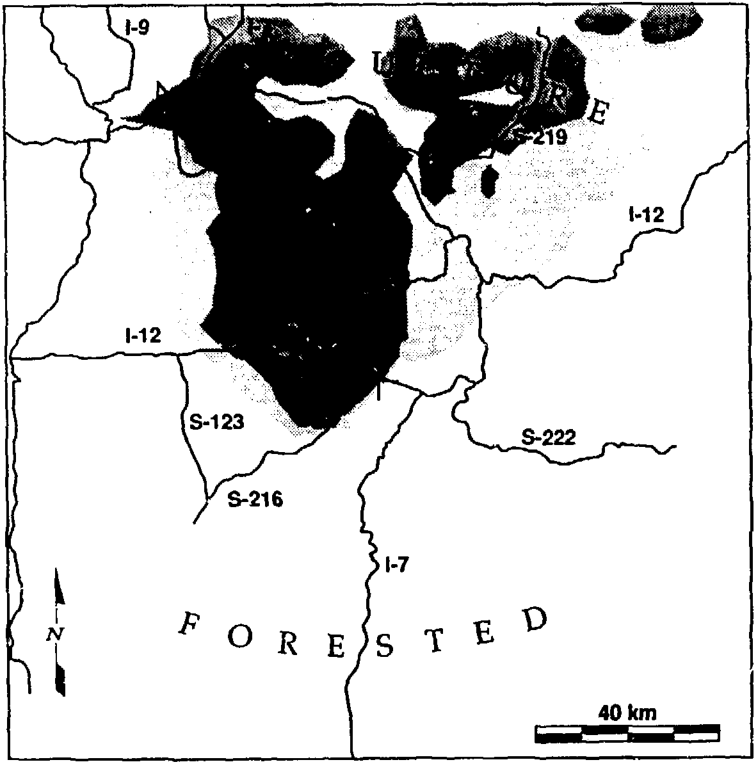

Remarks:
Inhalation pathway
50 year committed
effective whole body dose

Integrated:
Feb. 22, 89 1700 Z
to Feb. 24, 89 0100 Z

Material:
CS-137 at 1.5 m

Contour values
(in mSieverts)

■ > 10^{-1}
Area covers 38 sq. km.

▨ > 10^{-3}
Area covers 4037 sq. km.

□ > 10^{-5}
Area covers 7743 sq. km.

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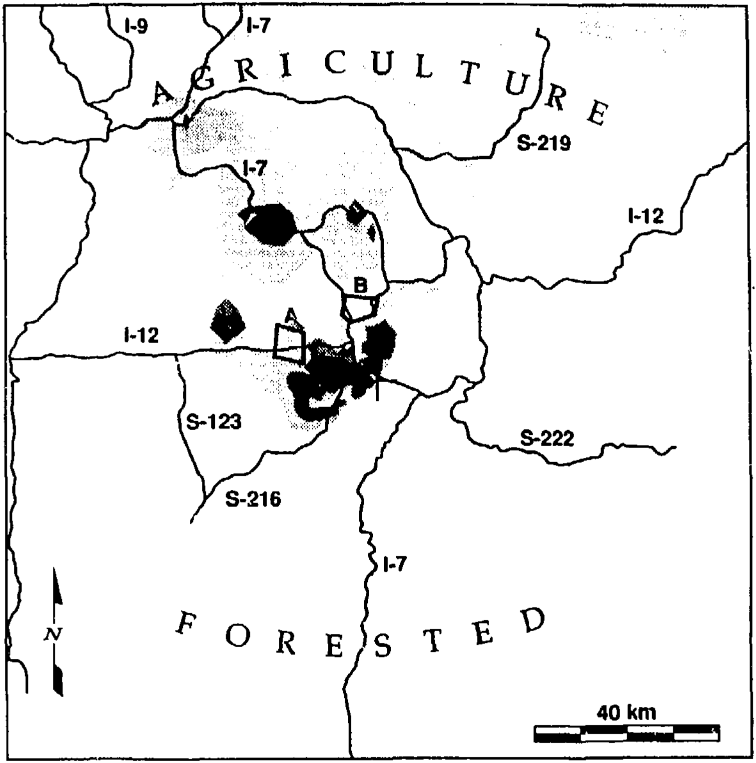


Remarks:

Cumulative deposition

Integrated:
Feb. 22, 89 1700 Z
to Feb. 24, 89 0100 Z

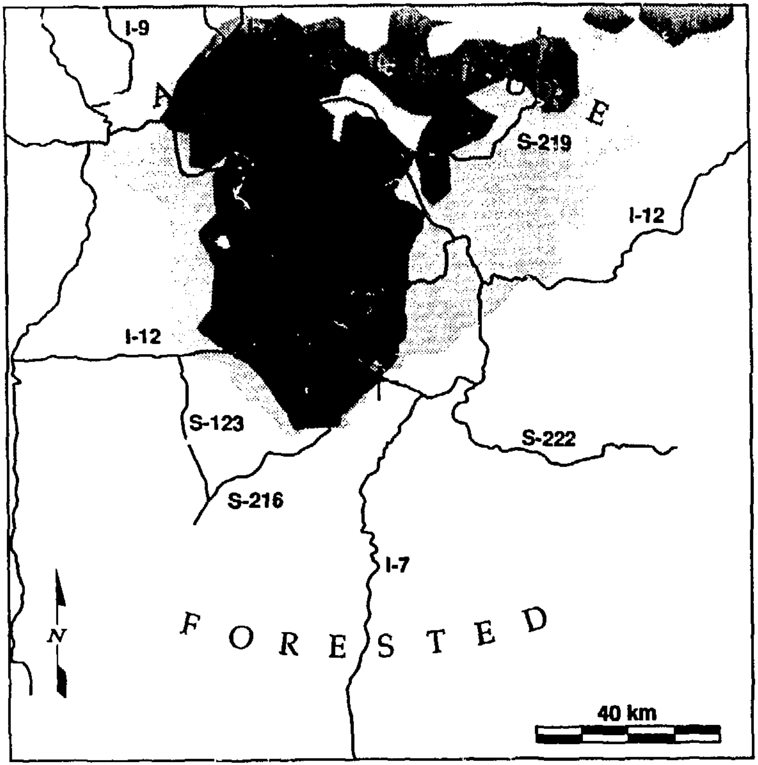
Material:
CS-137 at 0.0 m

Contour values (in Bq/m^2)

■ > 10^5
Area covers 60 sq. km.

▨ > 10^4
Area covers 361 sq. km.

░ > 10^3
Area covers 2729 sq. km.



Remarks:

Air immersion pathway
50 year committed
effective whole body dose

Integrated:

Feb. 22, 89 1700 Z
to Feb. 24, 89 0100 Z

Material:

XE-131 at 1.5 m

Contour values
(in mSieverts)

■ $> 10^0$

Area covers 41 sq. km.

▩ $> 10^{-2}$

Area covers 3926 sq. km.

░ $> 10^{-4}$

Area covers 7544 sq. km.

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Remarks:
Inhalation pathway
Combined I-131,
CS-137, XE-133
50 year committed
effective whole body dose

Integrated:
Feb. 22, 89 1700 Z
to Feb. 24, 89 0100 Z

Material:
I-131, CS-137,
XE-133 at 1.5 m

Contour values
(in mSv)

■ $> 10^1$
Area covers 302 sq. km.

■ $> 10^0$
Area covers 1983 sq. km.

▨ $> 10^{-1}$
Area covers 6078 sq. km.

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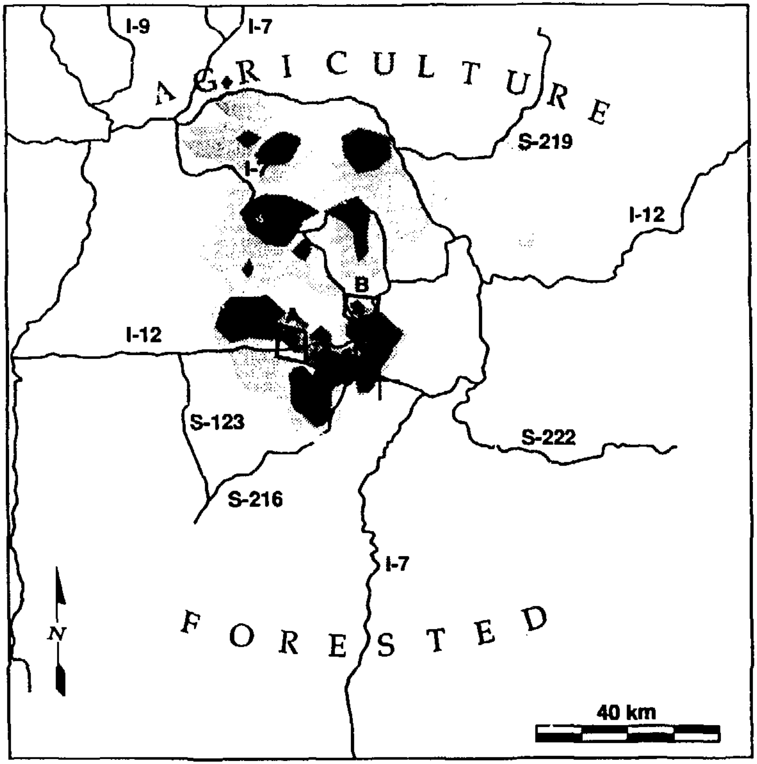


Remarks:

Combined I-131 & CS-137
effective whole body
ground exposure dose rate

Integrated:
Feb. 22, 89 1700 Z
to Feb. 24, 89 0100 Z

Material:
I-131, and CS-137
at 0.0 m

Contour values
(in mSv/s)

■ $> 10^{-5}$

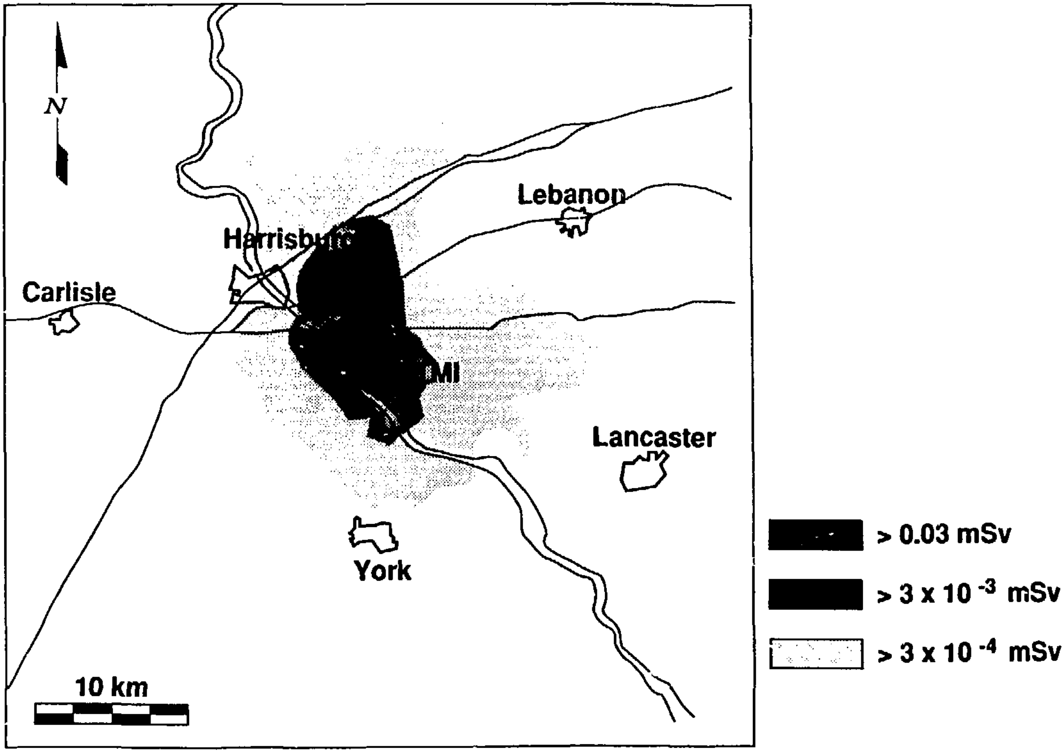
Area covers 118 sq. km.

■ $> 10^{-6}$

Area covers 803 sq. km.

▨ $> 10^{-7}$

Area covers 2952 sq. km.



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