

Emergency Response Planning for Radiological Releases¹

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ABSTRACT

The emergency management planning tool RISK-RDD was developed to aid emergency response planners and decision makers at all levels of government to better understand and prepare for potential problems related to a radiological release, especially those in urban areas. Radioactive release scenarios were studied by using the RISK-RDD radiological emergency management program. The scenarios were selected to investigate the key aspects of radiological risk management not always considered in emergency planning as a whole. These aspects include the evaluation of both aerosolized and nonaerosolized components of an atmospheric release, methods of release, acute and chronic human health risks, and the concomitant economic impacts as a function of the risk-based cleanup level.

INTRODUCTION

Radioactive materials are used extensively in industrial environments, medical applications, and research programs. The availability and pervasiveness of these materials, whether in a product or waste form, has always been a public safety concern. The accidental or intentional airborne release of radioactive material to the environment has ramifications in a number of areas. Of immediate concern is the location of any contamination, its movement, and the acute human health risk posed to nearby individuals in the short term. Longer-term concerns include the determination of affected areas and their contamination levels, the chronic human health risk, and the potential economic impacts that may be incurred as a result of intervention and cleanup.

The emergency management planning tool RISK-RDD was developed to aid emergency response planners and decision makers at all levels of government to better understand and prepare for such potential problems related to a radiological release, especially those in urban areas. Based on a geographical information system (GIS) platform that allows for visualization of the affected area, RISK-RDD was used to evaluate a range of such releases that might be the result of workplace accidents, transportation accidents, or terrorist events. For this exercise, the focus was on showing how RISK-RDD can be used to investigate the potential impacts from cleanup decisions in the longer term.

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APPROACH

The cleanup of a contaminated area after a radioactive material release is dependent on a variety of factors, including the level of contamination, the physical and chemical properties of the material itself and the contaminated area, the contaminated area land use (e.g., commercial, business, retail, industrial, residential, and/or agricultural), and the relative importance of the problem compared with other current political and social issues. To make informed decisions, responsible officials need to properly assess the different options that may be available. The first step in such a process is to determine the extent of the problem. Once the problem has been defined, potential options and their ramifications must be explored to find a suitable resolution.

The two major long-term concerns following a radioactive material release are human health and economic impacts. A series of atmospheric release scenarios to illustrate the issues faced by decision makers was examined by using the prototype RISK-RDD code, highlighting the choices that needed to be addressed. The scenarios, which could be the result of an industrial or transportation accident or an intentional release, were designed to sample a wide range of potential impacts by varying the type of radionuclide involved, the method of release, the aerosolized component of the release, and the atmospheric conditions.

The International Atomic Energy Agency (IAEA) has summarized the radionuclides used in radioactive sources in a wide range of applications [1]. The agency developed a 5 Level categorization scheme (Categories 1 through 5) based on the relative hazard of each type of radioactive source, with Category 1 sources posing the largest risk should a release occur. Category 1 sources contain the largest amount of radioactivity of the more hazardous radionuclides. However, little risk is posed by these sources when handled properly and used for their intended application.

Category 1 and 3 sources of Cs-137 and Am-241, respectively, were selected for use in the analysis. These two radionuclides represent the two most dangerous classes of radiation hazard from most industrial, medical, and research sources. The risk posed by Cs-137 is an external gamma radiation hazard. Nearby individuals are exposed to such radiation whether the radionuclide is airborne or deposited on the ground. Most Category 1 and 2 sources are gamma emitters. On the other hand, Am-241 is an internal alpha radiation hazard. When inhaled or ingested by an individual as an airborne release passes by or ground contamination is resuspended, Am-241 can emit an alpha particle (alpha radiation) as its primary method of decay. Other types of sources include beta or neutron emitters. Beta emitters may be more of an internal hazard, but existing mobile sources are less hazardous than the larger alpha sources. Neutron radiation can be extremely hazardous, but existing neutron sources, other than large, immobile generators, are a relatively small danger compared with the gamma and alpha sources.

How radioactive contamination is released to the environment plays a significant role in the extent of any impacts. If radioactive material is spilled on the ground, most of the material will remain in the area in a more concentrated amount than if released violently to the atmosphere as the result of a fire or explosion. Ground-level atmospheric releases with and without the involvement of a fire or an explosion were considered in the analysis. The fire conditions modeled were consistent with the amount of energy given off by a small diesel fuel fire that

could result from a transportation accident involving a large truck. The size of the explosion modeled was in the range of a few pounds of high explosive.

Atmospheric conditions play a large role in the dispersion of airborne material. Neutral stability conditions are common across the United States. Neutral conditions with a wind speed of 4-m/s were used in the analysis and compared with the impacts if stable conditions with a 1-m/s wind speed had occurred during a release.

The physical form of any material released plays a large role in how far it might be dispersed and the ensuing long-term impacts. Source material in a powder form is much more susceptible to becoming airborne and widely dispersed than larger pieces or chunks of solid material such as metals or ceramics. Thus, the amount of the radioactive sources studied that became aerosolized was varied in the analysis. The remaining material was distributed in the vicinity of the postulated release according to how the source was assumed to be released.

The long-term human health impacts assessed were assumed to occur after passage of the airborne contaminant plume following a hypothetical release. The estimated 1-year dose from exposure to external radiation from contaminated ground (groundshine), exposure to external radiation from resuspended contamination (cloudshine), and internal exposure from inhaled resuspended contamination were included. For the purposes of this analysis, individual receptors were assumed to be present one-third of the time without shielding.

RESULTS AND DISCUSSION

In the days, weeks, months, and potentially years after a radioactive material release to the environment, the affected community must respond in a manner that minimizes human health risk while trying to return to normal life. Normal life implies that affected areas are returned to the same livable conditions prior to the contamination event. Decision makers will be required to make choices in the long-term as to how cleanup is to be addressed, including decisions regarding what decontamination technologies to use and what cleanup levels to attain. In part, these decisions will examine current and pending government regulations and past and ongoing experience from cleanup of Cold War legacy contaminated industrial sites, the safe shutdown of nuclear facilities at the end of their operational life, and prior accidental releases. This paper is intended to give some perspective on the relative differences in restoration efforts based on cleanup levels. Potential cleanup levels based on an individual human exposure of 1 to 100 mrem/year were used for the comparisons.

The weather conditions at the time of an atmospheric release of radioactive material have a significant affect on the extent of contaminant spread. Fig. 1 presents the affected area, defined as the area in which an individual would receive a given annual dose or higher as a function of the cleanup criteria for a release involving Am-241. A similar set of curves was calculated for a Cs-137 release. In each case, all available radionuclide material was assumed to be aerosolized and transported downwind. The effect of dispersion is evident with the stable weather conditions resulting in a larger contaminated area for a given annual dose than that from neutral conditions. In general, it was noted that the affected area with a cleanup criteria of 1 mrem/yr was more than 200 times the size of the affected area with a cleanup criteria of 100 mrem/yr.

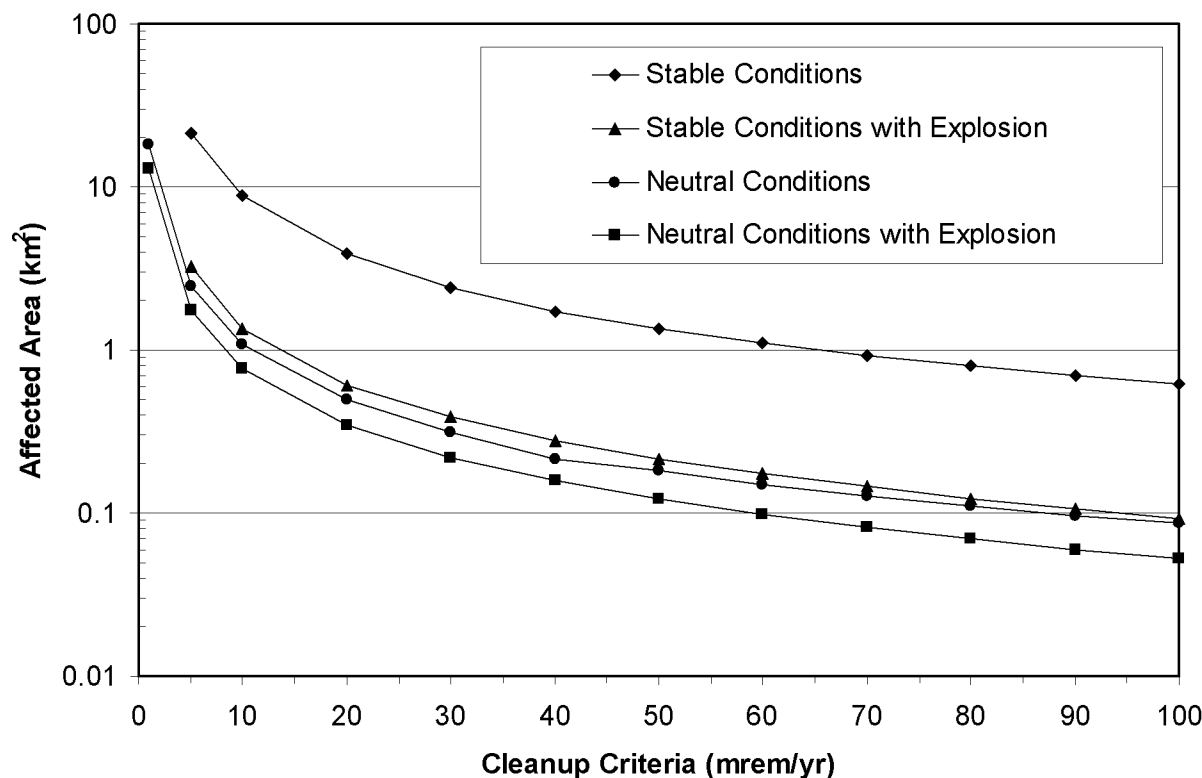


Fig. 1. Influence of aerosolized average particle size on the affected area

Stable conditions do not disperse airborne material as rapidly as neutral conditions. Thus, the overall effect is that more material deposits on the ground closer to the release point due to higher air concentrations as the plume travels downwind. This effect is seen further in Fig. 1 where the release was initiated by an explosion. The explosion causes an initial dispersion of the material before atmospheric transport and dispersion, resulting in lower ground concentrations and the concomitant lower annual doses. Also notice that the explosive release has a larger relative effect on stable weather conditions than neutral conditions. Scenarios involving fire resulted in similar levels of ground contamination (and therefore long-term dose) as those for the simple release without explosion. The size of such a fire only affects resulting ground concentrations in the immediate location of the release, slightly diluting air concentrations and shifting ground concentrations downwind.

Higher contaminant ground concentrations can also result if the particulates constituting the aerosolized component of a release have a larger average diameter and/or when it is raining due to washout of the plume. Large particle sizes of the same material will deposit faster due to gravitational settling because they are heavier, and larger particles have a higher cross-section for being impacted and driven to the ground by raindrops. Fig. 2 shows an example of the effect of average particle size on the affected area for a given dose during a constant rainfall of 2 mm/hr.

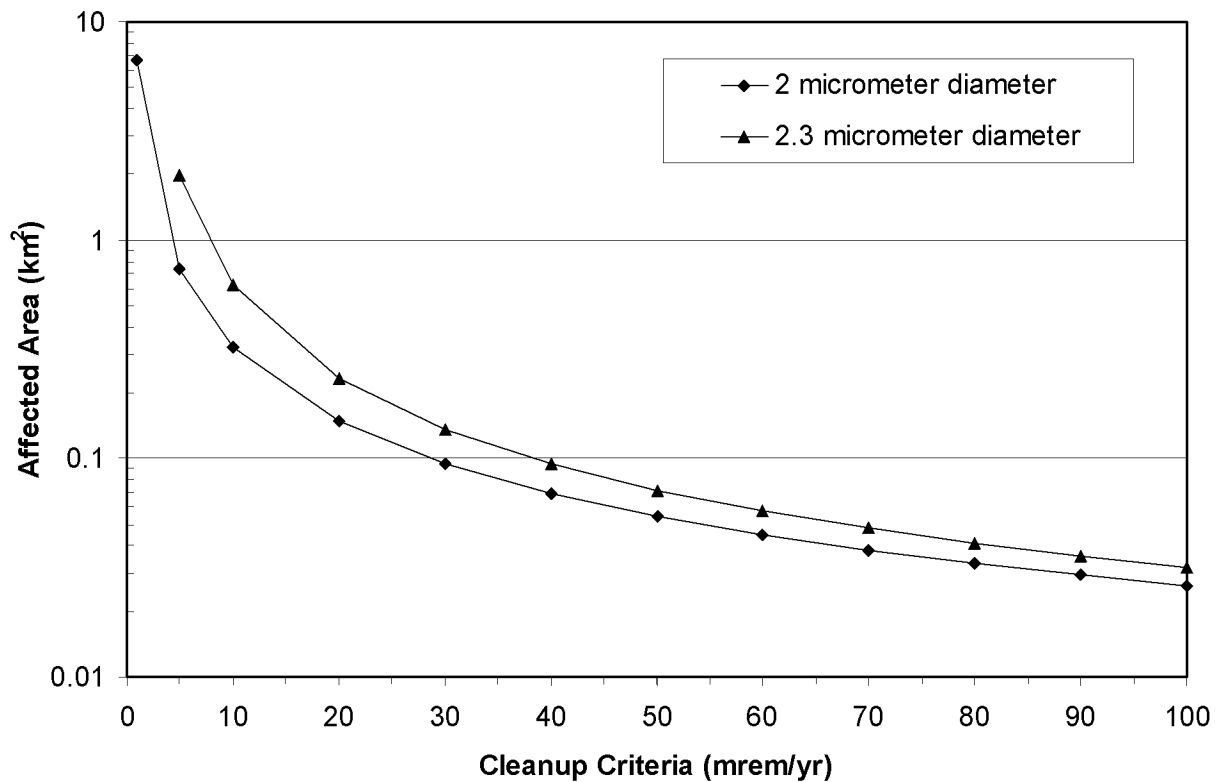


Fig. 2. Example of the effect of average particle size on the affected area for a given dose during constant rainfall

All of the radioactive material present in a release may not become aerosolized and airborne. Even in the case of an explosion, a significant amount of the source may be left in the vicinity of the release. Fig. 3 shows an example of an area where the individual dose was estimated to exceed 100 mrem/yr following an Am-241 release with a significant amount of the material distributed around the release location. Little external exposure from Am-241 is expected, and in the same case for Cs-137, no acute radiation fatalities were estimated using RISK-RDD when most of the source material was left at the release location. The acute radiation dose model used is that developed further for the U.S. Nuclear Regulatory Commission after the Chernobyl disaster [2]. However, dose rates were in the several rem/hr range within 2 m of the source for Cs-137. Such a nonaerosolized component of a release is a significant hazard to first responders and might require long-term interdiction of the area if the material cannot be easily removed. When portions of the radioactive source material are distributed in the near vicinity of the release rather than dispersed downwind, the ratio of the 1-mrem/yr to 100-mrem/yr affected area becomes less than 200, depending on the amount and distribution of the nonaerosolized component.

In the long term, the response to minimize human health risks will result in economic impacts and cleanup activities. Economic impacts from a radiological event occur when land and property require decontamination or disposal and are temporarily or permanently unavailable. By

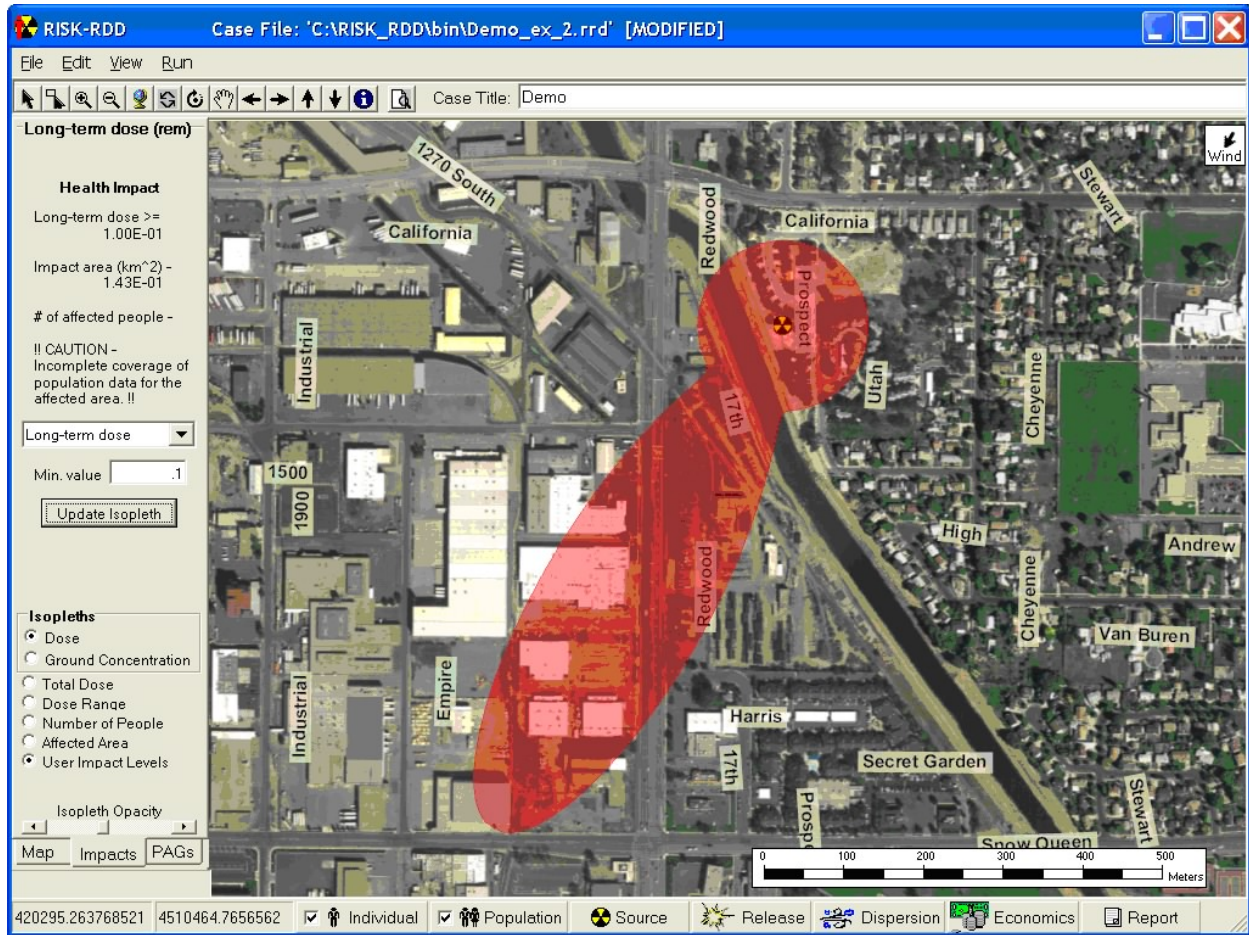


Fig. 2. Area for long-term dose exceeding 100 mrem/yr from downwind deposited contamination and nonaerosolized material

using the IMPLAN model [3] and user-input dose limits, RISK-RDD estimates the direct and indirect business disruption impacts from the loss of use of land and property, including lost income and jobs, and the costs associated with cleanup and reconstruction. Income and jobs are lost directly as a result of the loss of use of the affected area, as well as indirectly as a result of the loss of income and jobs in other geographic locations that are economically tied to the affected area. Decontamination (cleanup) costs were determined on the basis of previous decontamination projects involving hazardous materials. Fig. 1 and Fig. 2 show how the size of the area of concern changes with different release scenarios and cleanup criteria. Fig. 4 shows an example of how interdiction of the affected area for 1 month following an environmental release might affect the economy. In this example, a mix of economic sectors, including transportation, utilities, transportation, manufacturing, services, and retail were assumed to be interrupted in an urban area of 500,000 to 1,000,000 people.

Decisions involving cleanup methods must take into account the size of the contaminated area to be remediated and the waste generated by the cleanup method. Waste volumes were estimated based on user input of waste generation rates to RISK-RDD for a given cleanup technology. In the case with the explosive release of Cs-137, a cleanup level of 30 mrem/yr was selected as an

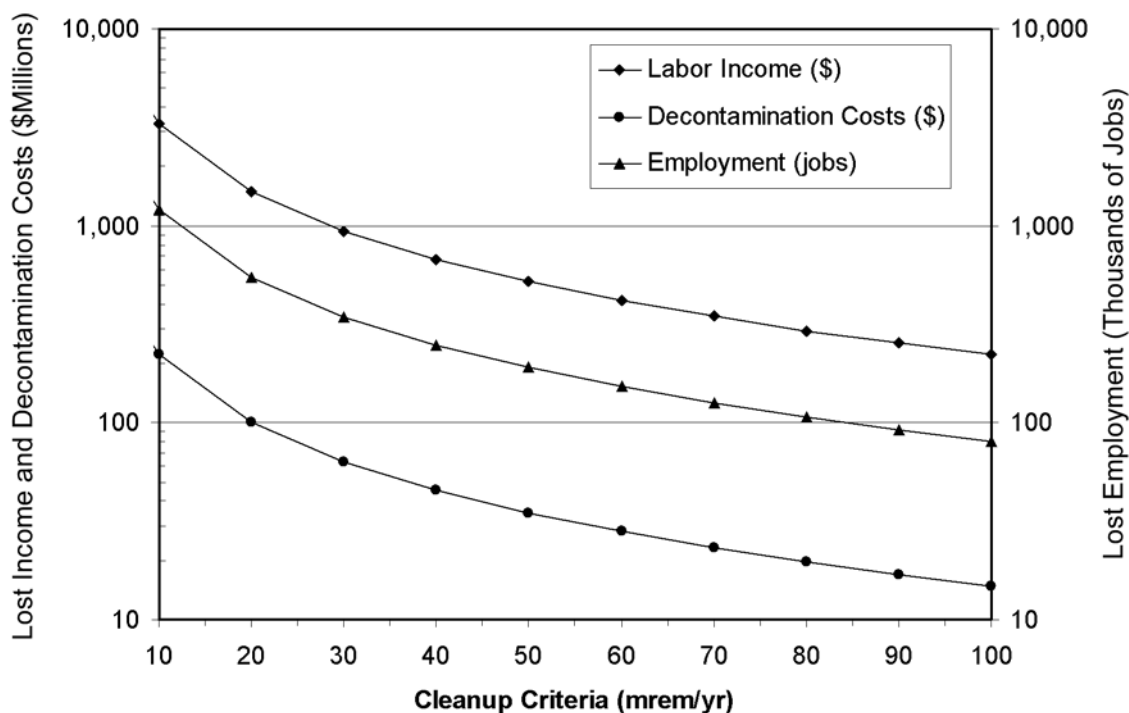


Fig. 3. Economic impacts as a function of cleanup criteria for a large urban area

example calculation. An affected area of 0.16 km^2 required removal of 0.8 Ci to meet this criterion.

If removal of 1 cm of surface material were required to obtain this objective, approximately $1,600 \text{ m}^3$ of waste would be generated. If a cleanup technology generates 1 gallon of liquid waste per square foot, then approximately $6,500 \text{ m}^3$ of waste would be generated.

CONCLUSION

Planning for long-term cleanup following a radioactive material release can be accomplished using the RISK-RDD code. Such planning for an urban area must first take into account the range of potential release scenarios. These scenarios provide an understanding of how the material is dispersed and the resulting ground contamination levels. It was shown that higher ground concentrations, therefore a bigger long-term problem, would result due to stable weather, precipitation events, and larger particle sizes of the aerosolized material. Weather conditions also have a larger influence on deposited amounts than does an explosive versus nonexplosive release. In this study, for a 100% aerosolized radioactive material release, the area of concern is greater than a factor of 200 larger in size with a cleanup criteria of 1 mrem/yr rather than 100 mrem/yr. This comparison is smaller for cases in which there is a nonaerosolized component dispersed in the near vicinity of the release. Interdiction of the affected area for a mid-size city for 1 month could result in millions of dollars in lost income and tens of thousands of lost jobs.

REFERENCES

1. International Atomic Energy Agency, 2003, *Categorization of Radioactive Sources*, IAEA-TECDOC-1344, Radiation Safety Section, Vienna, Austria, July.
2. Abrahamson, S., et al., 1989, *Health Effects Model for Nuclear Power Accident Consequence Analysis, Low LET Radiation*, Rev. 1, Part II, Addendum 1, NUREG/CR-4214, U.S. Nuclear Regulatory Commission, Washington, D.C.
3. MIG, Inc. (Minnesota IMPLAN Group, Inc.), 2005, *2002 IMPLAN Data*, Version 0.2.15.2005, CD-ROM, MIG, Inc., Stillwater, Minn.