WASH – 1400
(NUREG-75/014)

Reactor Safety Study

An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants

Appendix VI

United States Nuclear Regulatory Commission

October 1975

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

November 1975

Dear Sir:

The Reactor Safety Study, initiated by the AEC, has completed its work under the sponsorship of the U.S. Nuclear Regulatory Commission. The work was performed by a study group headed by Professor Norman C. Rasmussen of the Massachusetts Institute of Technology. A draft report was circulated in August 1974 and comments were received from 87 individuals and organizations representing many diverse viewpoints and fields of expertise. These comments were very helpful in completing the final report "An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants," WASH-1400 (NUREG-75/014) of October 1975.

In a recent public statement, William A. Anders, Chairman of the U.S. Nuclear Regulatory Commission stated:

> "The Commission believes that the Reactor Safety Study report provides an objective and meaningful estimate of the public risks associated with the operation of present-day light water power reactors in the United States. The final report is a soundly based and impressive work. Its overall conclusion is that the risk attached to the operation of nuclear power plants is very low compared with other natural and man-made risks. The report reinforces the Commission's belief that a nuclear power plant designed, constructed and operated in accordance with NRC's comprehensive regulatory requirements provides adequate protection to public health and safety and the environment. Of course, such regulatory requirements must be continually reviewed in the light of new knowledge, including that derived from a vigorous regulatory research program."

A copy of the report is being forwarded for your information and use.

Sincerely,

Saul Levine

Saul Levine
Project Staff Director
Reactor Safety Study

Enclosure:
Final Report

WASH-1400
(NUREG 75/014)

CALCULATION OF REACTOR ACCIDENT CONSEQUENCES

APPENDIX VI
to
REACTOR SAFETY STUDY

U.S. NUCLEAR REGULATORY COMMISSION
OCTOBER 1975

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Section I

Introduction

This appendix of the Reactor Safety Study describes the input data and mathematical models employed to calculate the consequences of a potential release of radioactive material in the event of a nuclear power plant accident. Emphasis has been placed on documenting the rationale and referencing the source material underlying these inputs and models. In the course of this work, it has become increasingly clear that the consequence model is complex, with dependencies between many different scientific and medical disciplines, and that, in many areas, the available base of data is limited. The model described herein represents a reasonable assessment of consequences considering the state of knowledge in each subject. Future refinements should reduce the uncertainties, but it is believed at this time that the best-estimate values of the probabilities and magnitudes of the consequences should not greatly change from the values reported herein.

To assist in the development of the consequence model, the Reactor Safety Study has solicited the advice of many nationally recognized consultants in the many disciplines involved. In particular, an advisory group on health effects was formed; its membership is listed in section 14 of this appendix. The advisory group was unanimous that the selected model and input data were reasonable given the current state of knowledge. Of course, as would be expected in such a complex area, there were some conflicting opinions within the group over some details; however, these differences did not detract from the unanimity of opinion on the adequacy of the overall health model. The judgments and opinions expressed in this appendix are nonetheless the responsibility of the Reactor Safety Study.

It is the objective of the study to assess the risk from commercial nuclear power plants in as realistic a way as can reasonably be attained and to bound this assessment with upper and lower values. It is important that the estimate be as realistic as is reasonably attainable, in order to provide a proper perspective on potential risks. This realism is especially needed where risk comparisons are made as in chapter 6 of the Main Report.

A schematic outline of the model is shown in Fig. VI 1-1. The starting point for the calculation is the quantity of the radioactive material that could be released from the containment to the environment in the event of a nuclear power plant accident. The spectrum of releases to the environment are discretized into the nine PWR[1] and five BWR release categories as stated in Table VI 2-1, each with its associated probability of occurrence and release magnitude. Though the probability values that were developed in preceding appendices included estimated confidence bounds, these bounds are not propagated in the consequence model. However, they are used to estimate the confidence bounds on the results reported herein. The release magnitudes are used as best-estimate values, although, as discussed in the Main Report, they are believed to be conservative. The meteorological model computes the dispersion of radioactive material in terms of concentration in the air and on the ground as a function of time after the accident and distance from the reactor. The model used to compute dispersion is described in section 4, and the data that support its selection are presented in Appendix A. The model includes the following factors:

1. The decay of radioactivity as a function of time after the accident.

2. A standard Gaussian dispersion model that has been modified to include the effects of thermal stability, wind speed, and precipitation as a function of time after the accident. The model includes neither the temporal variation of wind direction nor the effect of wind shear.

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[1]One PWR release category was subdivided into two releases to more properly represent the range of heat rates included within the category.

3. Dry deposition by contact between the cloud and the ground and wet deposition by washout due to the temporal variation in the occurrence of precipitation, as described in section 5 and Appendix B.

4. The temporal variation of weather parameters (stability, wind speed, and precipitation) are obtained by using 90 stratified samples from 1 year's weather data from applicable reactor sites. The diurnal and seasonal variations of the mixing layer are included. The details of the sampling scheme are described in section 13.

5. The effects of the plume lifting off the ground due to the release of sensible heat. Latent heat and radioactive heating are not included. The plume is not permitted to penetrate the mixing layer.

Having computed the concentrations of radioactivity in the air and on the ground, the model then computes the potential doses that could accrue from the following potential modes of exposure:

1. External irradiation from the passing cloud. This exposure would occur over a period of about one-half to a few hours.

2. Internal irradiation from inhaled radionuclides. While the inhalation would take place over the same time period as external irradiation from the passing cloud, the dose accumulated would be controlled by the residence time of the various radionuclides in the various parts of the body.

3. External irradiation from radionuclides deposited on the ground.

4. Internal irradiation from the inhalation of resuspended radionuclides that had been deposited on the ground. This exposure mode would not contribute significantly to predicted doses.

5. Ingestion of radionuclides from contaminated crops, water, and milk. Since this type of exposure could be controlled by constraints placed on consumption until levels of radioactivity are below maximum permissible concentrations, it would not contribute significantly to predicted doses.

All these different modes of exposure and the corresponding dosimetric models are discussed in section 8, with supporting data supplied in Appendices C through E.

The risk for the first 100 commercial nuclear power plants is calculated by using the following considerations. Meteorological data were obtained from six representative reactor sites, and each of the 68 sites was assigned to one of the six meteorological data sets to form a composite site representative of those reactors that are subject to similar weather. The meteorology for these six sites is described in section 5.

The distribution of people as a function of azimuth and distance from the reactor was obtained from 1970 census data. The populations in 22.5^{o} sectors associated with the reactors assigned to a particular meteorological data set were combined to form a composite population distribution and its associated probability for that weather set. The details of this combination are described in section 10. It was assumed that people located within 25 miles downwind of the reactor would be evacuated in the event of an accident. By statistically analysing evacuation data (Appendix J), an evacuation model was developed as described in section 11.

The health effects models are described in section 9 with supporting data in Appendices F through I. The costs of decontaminating land or relocating the resident population are calculated with models described in sections 11 and 12 with supporting data in Appendix K.

The overall accident set is computed by convoluting the dispersion of radioactive material associated with the 10 PWR and 5 BWR release categories by using the 90 weather samples from each of the six sets of meteorological data over each of 16 population sectors for each of the six combined population distributions. These 130,000 hypothetical accidents are then ranked to generate complementary cumulative distribution functions for each of the potential consequences.

The results of the calculations are presented in section 13. Some additional studies are presented to show the sensitivity of specific consequences to important input parameters. In general, interdependencies between two parameters have not been assessed, and the study recommends more work in this area.

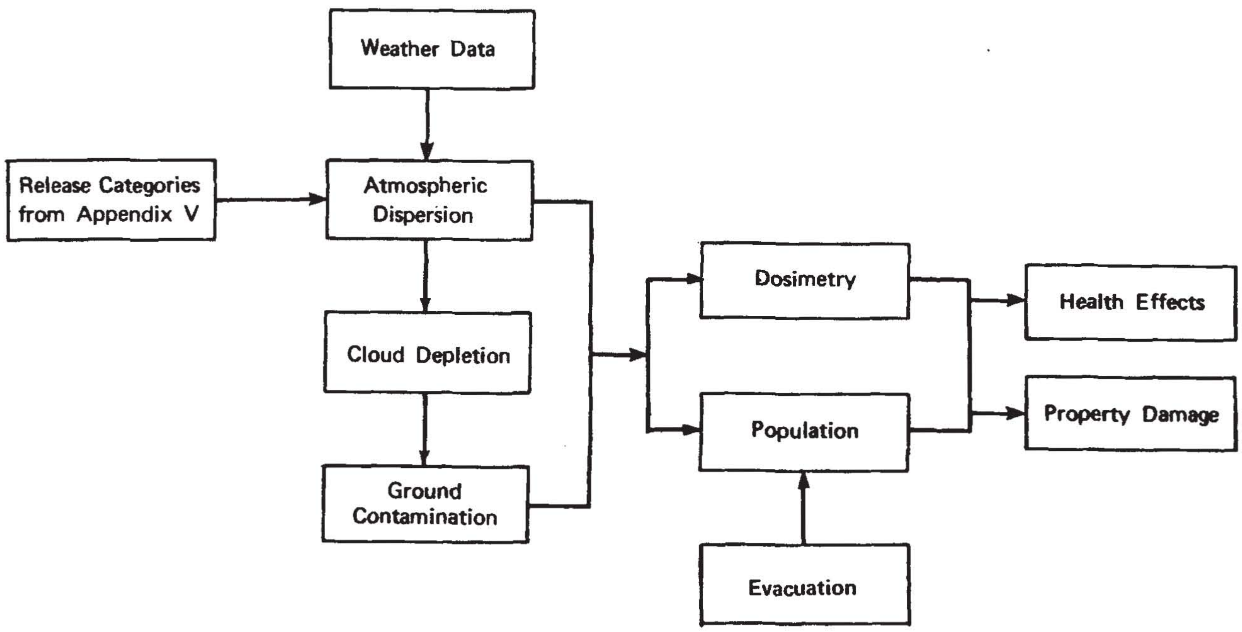

Fig VI 1-1 Schematic Outline of Consequence Model