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The Consequence Model of the German Reactor Safety Study

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The consequence model developed for phase A of the German Reactor Safety Study (RSS) is similar in many respects to its counterpart in the U.S. RSS[1]. As in that previous study, the model describes the atmospheric dispersion and transport of radioactive material released from the containment during a postulated reactor accident, and predicts its interaction with and influence on man. Differences do exist between the two models however, for the following reasons:

- to more adequately reflect central European conditions
- to include improved submodels
- to apply additional data and knowledge that have become available since publication of the U.S. RSS

The consequence model as used in phase A of the German RSS will be described here highlighting differences between it and the U.S. model. Revisions and improvements made in phase B of the study will be reported in subsequent papers.

A schematic view of the computational inputs and procedures utilized in the model is given in Figure 1. Engineering analyses performed by the GRS provide a description of postulated reactor accident releases in terms of their estimated frequency of occurrence, magnitude, timing and heat content. These data are input to an atmospheric dispersion and deposition submodel to calculate air and ground concentrations of radionuclides at downwind locations as a function of time following the accident. Weather data from each of four selected sites is incorporated in the form of hourly recorded wind speeds, thermal stability and precipitation occurrence for a one-year period[+]. The four sites were chosen to represent the variability of climatic and topographic conditions found in Germany, and correspond to the following general areas:

- North German Plains
- Upper Rhine Valley
- South German Highlands
- River Valleys

From the year's data at each site, 115 weather sequences are sampled beginning every 3 days plus 5 hours. For each start time, succesive hourly recordings are

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[+]The wind direction, however, is assumed to be invariant during and following the release.

incorporated to describe the changing pattern of dispersion and transport of the released cloud of radioactive material as it moves away from the reactor ++. Concentrations within the cloud are depleted by deposition (both wet and dry) and radioactive decay, using essentially the same coefficients as in the U.S. RSS. The atmospheric dispersion parameters (σ_y, σ_z) assumed are based on German experimental data and are, due to the higher roughness in the vicinity of reactor sites) somewhat higher than those used in the U.S. RSS.

The calculated air and ground radionuclide concentrations are input to a dosimetry submodel to estimate the radiation exposure of the public from the following pathways:

- external radiation from (1) airborne radionuclides in the cloud, and (2) radionuclides deposited on the ground.
- internal radiation from (1) radionuclides inhaled from the passing cloud, (2) ingested radionuclides, and (3) inhaled resuspended radionuclides.

As a preliminary calculational step, potential doses from ground exposure only are estimated and compared to dose criteria to determine what, if any, public protective actions would be implemented. Rather than the immediate large-scale evacuation of persons close to the reactor assumed in the U.S. RSS, the German study assumes that persons in highly affected areas would first be sheltered, and then evacuated by emergency personnel. The protective actions submodel incorporated is presented schematically in Figure 2. Dose criteria for countermeasures in response to chronic exposure (land, crop and milk interdiction, relocation, and decontamination) are essentially the same as used in the U.S. RSS. With protective measures determined, actual organ doses are then calculated using the dose factors derived in the U.S. RSS.

Population data for each of 19 German reactor sites was input to the model using a polar coordinate grid centered at the reactor, with 36 sectors (10°) and 18 radial intervals extending to 540 km. Actual site population data was used to a distance of 80 km. Beyond this, to a distance of 540 km, a uniform population density of 250 persons/km^2 (approximate average for middle Europe) was assumed. Similar

++The wind direction probability distribution is assumed uniform at all sites. Therefore the concentrations calculated using each weather sequence are rotated 36 times (every 10°) so that they impact each population sector.

to the U.S. RSS, any radioactive material remaining in the cloud when it reaches 540 km is assumed to be uniformly deposited over an area extending to 2500 km, *with an average (uniform) population density of 25 persons/km^2.*

Based on the calculated organ doses for downwind individuals, and using the population data described above, the health effects submodel estimates the numbers of early and latent cancer fatalities and the collective genetic significant dose that would result from the accidental release. Early fatalities (observed within one year of the exposure period) would result only from very large acute doses of radiation, and are estimated in the Germann RSS based on the individual bone marrow dose[+] received within the first 7 days of exposure. The model incorporates a dose response function proposed by K.R. Trott with a linear normal slope, threshold level = 100 rad, LD_{01} = 250 rad, and LD_{50}[++] = 510 rad. This function differs from that assumed in the U.S. RSS (curve B for supportive medical treatment) which had a threshold of 320 rad and LD_{50} = 510 r. Latent cancer fatalities are calculated using a linear dose response model and ICRP[2] risk factors for dose to the bone marrow, mineral bone, lung, thyroid and breast. Additionally a risk factor for all remaining organs of 1 10^{-5} rem^{-1} was applied to the sum of the five highest organ doses not previously considered. Unlike the U.S. RSS no dose effectiveness factors for low doses and/or dose rates are assumed. Similarly no economic model is incorporated to estimate the potential extent of property damage associated with the accident release.

Estimated consequences resulting from particular combinations of accident type, weather sequence, and population sector are output from the health effects submodel. The associated freuquency of each particular combination, and therefore the estimated consequences, is given by the product of f_A, p_W and p_P where: f_A is the estimated frequency of occurrence for that type of accident, p_W is the estimated weather probability and p_P is the probability of the particular population sector. As in the

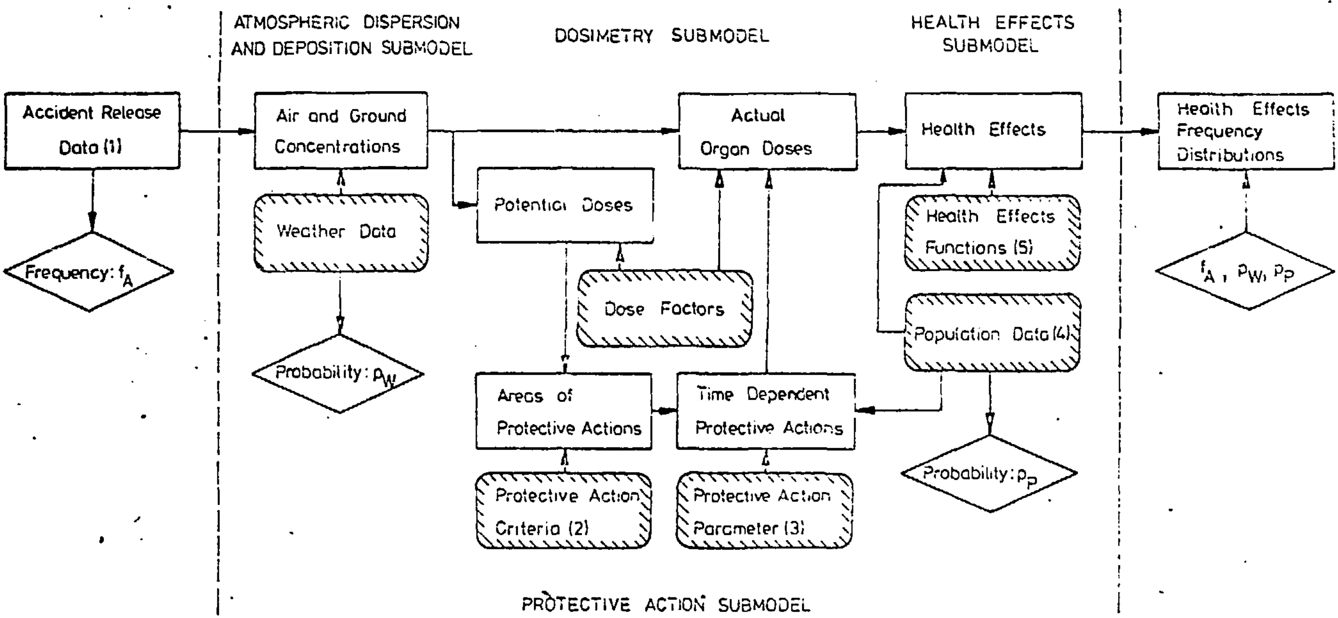
+The U.S.RSS estimated early fatalities on the basis of exposure to the bone marrow, lung and gastrointestinal tract. However, results of that study indicated that bone-marrow damage was the overwhelmingly dominant contributor.

++The dose that would be lethal to 50 percent of the population.

U.S. RSS, these estimated consequences and associated probabilities may be combined and presented in the form of ccdf's (complementary cumulative distribution functions)[+] for each consequence type. For comparison with natural risk levels, however, output may also be provided in terms of the incremental individual risk for each consequence type as a function of distance from the reactor. Further output options facilitate the determination of risk contributions from specific radionuclides, exposure pathways and organs, and provide deeper insight into the interrelations of all major parameters included in the model.

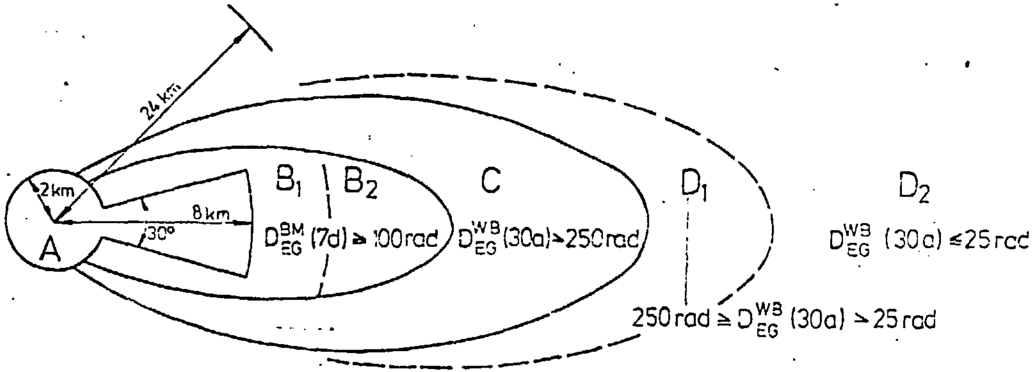
[+] A ccdf is a plot of the probability of equalling or exceeding a specified value versus the specified value.

Figure 1: Flow Schematic of the German RSS Consequence Model



(1) provided by Gesellschaft für Reaktorsicherheit/ Köln and München
(2) advised by K.H. Lindackers, TÜV-Rheinland / Köln
(3) timing parameters are based on protective actions simulation performed by H. Schnadt and J. Storch, Institut für Unfallforschung/ Köln
(4) compiled by Bonnenberg Drescher / Jülich
(5) advised by W. Jacobi and K.R. Trott, Gesellschaft für Strahlen und Umweltforschung/Neuherberg

Figure 2: Schematic of Protective Actions Model



D_{EG}^{BM} (7d) = 7 day outdoor bone marrow dose due to external exposure from ground

D_{EG}^{WB} (30a) = 30 year outdoor whole body dose due to external exposure from ground

Area	Protective Actions
A	Sheltering 2 hours after operator knows release will occur (t=2h). Evacuation at t=8h. Travel time 1.5h.
B_1	Sheltering at t=2h. Fast relocation takes place either 2 hours after cloud passage or t=14h, whichever is larger. Travel time dependent on population.
B_2	Normal activities. Fast relocation as in area B_1.
C	Normal activities. Relocation begins t=30d.
D_1	Normal activities. Decontamination to reduce D_{EG}^{WB} (30a) to 25 rad.

References

[1] Reactor Safety Study, App. VI: Calculation of Reactor Accident Consequences
WASH-1400 (1975)

[2] Recommendations of the International Commission for Radiation Protection
ICRP Publication 26
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