STOCHASTIC MODELS FOR INDIVIDUAL EXTERNAL DOSE RECONSTRUCTION OF POPULATION EVACUATED AFTER THE CHERNOBYL ACCIDENT

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INTRODUCTION

As a result of the Chernobyl accident, the residents of Pripjat and other settlements of the 30-km zone were affected by substantial amounts of radiation with the potential of delivering them significant radiation exposures before their evacuation. A reconstruction of individual doses of evacuees, including the determination of the uncertainty of the results, is of interest for epidemiological investigations. Dose rate measurements conducted in the time span between accident and evacuation and individual behavior data obtained by a questionnaire survey involving more than 30,000 evacuees allow for a reconstruction of individual external doses of a large fraction of the evacuated population. A first assessment has been reported in (1). The results revealed a large variation range for doses of different individuals, showing the importance of performing individual dose reconstructions.

This paper reports on developments and results of a second stage of individual external dose reconstruction. In particular, stochastic models based on Monte Carlo methods (2) were developed in order to determine uncertainty distributions of calculated doses from an assessment of the uncertainty of the data.

INDIVIDUAL DOSE RECONSTRUCTION FOR EVACUEES FROM PRIPJAT

In the city of Pripjat, dose rate measurements started two hours after the accident and lasted until after the completion of the evacuation two days later. They were conducted by two independent teams in intervals of 3.5 hours on the average. Figure 1 shows the position of the measurement points and dose rates measured 30 hours after the accident. Information on individual pre-evacuation histories of about 16,000 evacuees from Pripjat was obtained by a questionnaire survey (1). As indicated in Figure 1, the city was divided into eight sectors according to the measured open air doses and the evacuees were asked to reconstruct their location (indoor or outdoor, and in which sector) hour by hour until their evacuation.

The stochastic models developed for calculation of individual external doses are designed with a modular structure, separating the calculation of parameters which do not depend on individual behavior from the final computation of the individual dose. The uncertainty of the parameters are represented by frequency distributions of the parameter values. They are obtained from an assessment of data uncertainty by Monte Carlo sampling methods coded in the program PRISM (3). Taking the parameter values, the external dose for each individual is repeatedly (for example, 500 times) calculated, obtaining a frequency distribution representing its uncertainty. The individual external effective dose distribution E is calculated according to

$$E = C \cdot \sum_{h=1}^{h_{evac}} D(h,s) \cdot \Delta t \cdot L(h) \qquad \text{with } \Delta t = 1 \text{ hour.}$$

The summation extends over each hour h to the time h_{evac} the individual was evacuated; C is the conversion factor from absorbed dose in air to effective dose. The D(h,s) are uncertainty

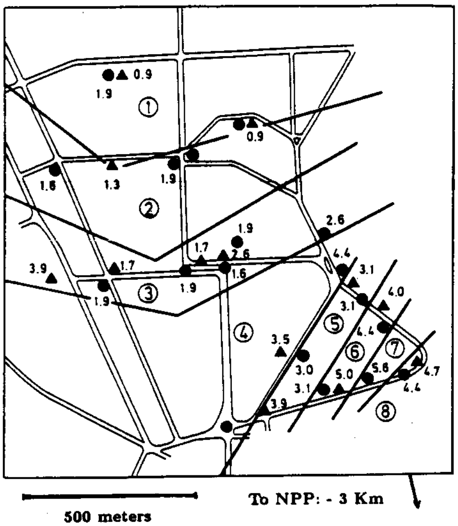

Figure 1. Plan of the city of Pripjat showing the points where dose rate measurements were performed by two independent teams (triangles respectively circles). Also indicated are dose rates in mGy/h measured 30 hours after the accident and the subdivision of the city into sectors for the questionnaire survey.

distributions of dose rate relative to reference area for the hour h and the sector s in which the individual was staying at this hour; the L(h) are location (shielding) factors appropriate for the indoor or outdoor location at which the individual had been at the hour h.

The distributions D(h,s) of dose rate relative to reference ara describe the uncertainty of the average dose rate of the sector and the variability of the dose rate within the sector. They are determined from the dose rate measurement data combined with information on the environment of each measurement point and an assessment of the uncertainties due to measurement errors and modifications by the environment. Incorporating time interpolations and Kriging methods (4) for interpolations in space in the PRISM code, the set of dose rate distributions D(h,s) is obtained. Figure 2 shows the distribution resulting 30 hours after the accident for one of the sectors of Pripjat.

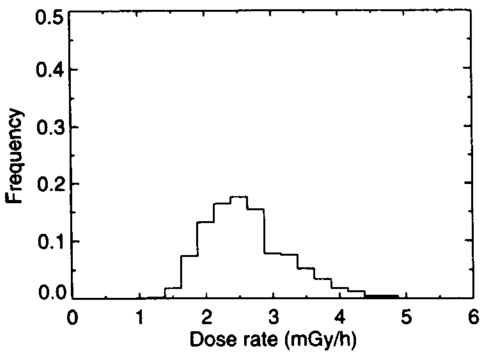

Figure 2. Frequency distribution of dose rate relative to reference area in sector 3 of Pripjat (compare Figure 1), 30 hours after the accident. The distribution reflects the uncertainty of the average dose rate of the sector and the variability of dose rate within the sector.

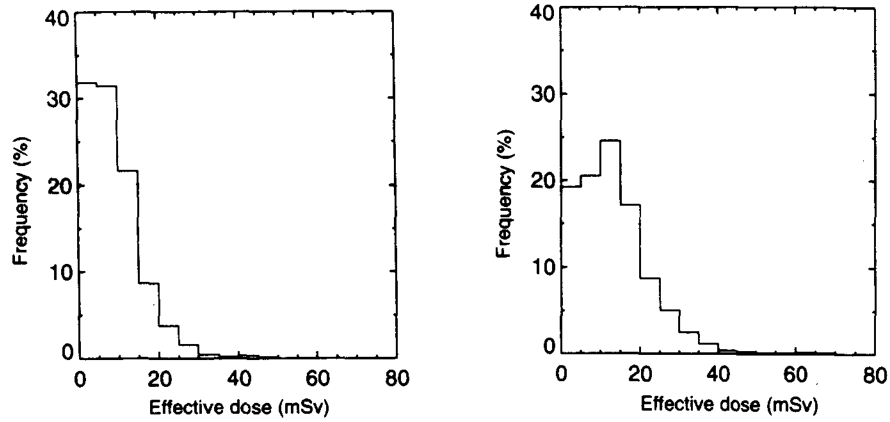

Figure 3. Relative frequency distribution of individual external effective doses of children (age group 3-7 years, left side) and adults (age group 25-55 years, right side) evacuated from Pripjat.

Location factors, defined as the ratio of dose rate at a particular indoor or outdoor location to the dose rate at a reference area (5), were calculated by Monte Carlo photon transport simulations for a specific five storey housing block typical for Pripjat. The results of separate calculations for different source configurations and energies provide a data base for estimating location factors and their uncertainty ranges. From a first analysis, for Pripjat a location factor of 0.05 with a range of 0.01 to 0.2 was estimated for indoors and of 0.8 for outdoor locations.

Based on the distributions of dose rates relative to reference area and the estimated location factors, distributions of individual external effective doses of 12,653 evacuees from Pripjat are being calculated. In a first step, deterministic calculations were performed with this data, obtaining a mean external effective dose for this population of 11 mSv, which is only slightly lower than the value of 11.5 mSv reported in (1). Frequency distributions of individual external doses for children and adults are compared in Figure 3. Children had been staying a larger fraction of time indoors, so that their external doses are generally lower.

CONCLUSIONS

The development of stochastic models which allow to determine uncertainty distributions of external effective dose individually has been discussed for population evacuated from Pripjat. Similar models are being developed for evacuees from the other settlements of the 30-km zone. The results will allow to obtain a clearer vision of values and uncertainty ranges of individual doses received by population from the near zone of the Chernobyl nuclear power plant before its evacuation.

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