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ATMOSPHERIC RELEASES FROM SEVERE NUCLEAR ACCIDENTS: ENVIRONMENTAL TRANSPORT AND PATHWAYS TO MAN: MODELLING OF RADIATION DOSES TO MAN FROM CHERNOBYL RELEASES

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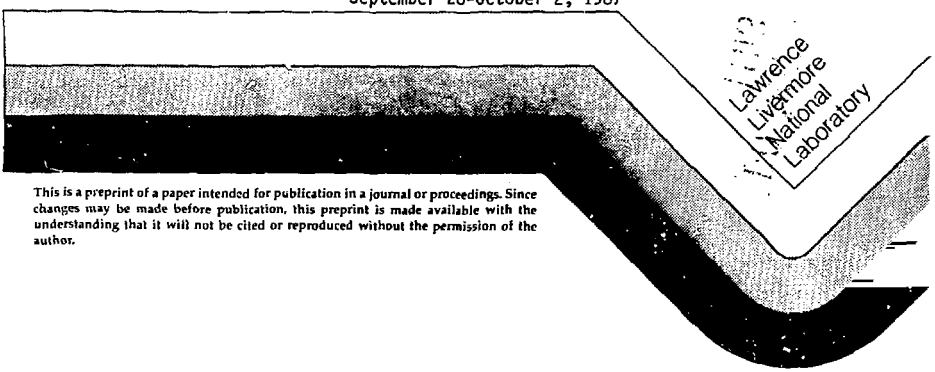

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1. ABSTRACT

The Chernobyl accident released a large amount of highly fractionated radioactive debris, including approximately 89 PBq of ^{137}Cs. We calculated the resulting collective dose commitment to the Northern Hemisphere via the pathways of external exposure and ingestion of radionuclides with food. In order to do this, we developed a rural/urban model of external dose and we used the PATHWAY model for ingestion. The results are a collective dose commitment of 630 000 person-Gy over the first year and 1 200 000 person-Gy over 50 years.

2. INTRODUCTION

The accident at Reactor 4 of the Chernobyl Nuclear Power Station resulted in the release of a very large amount of highly fractionated radioactive debris. Of the released material, it is now apparent that the more dosimetrically significant radionuclides are ^{137}Cs, ^{134}Cs, and ^{131}I. The approximate releases of these radionuclides were 89, 48, and 1700 PBq, respectively[1]; this calculation[2] is based upon the use of the PATRIC atmospheric transport model and measured concentrations of radionuclides in air in Europe and elsewhere throughout the Northern Hemisphere. These values are consistent with the integrated deposition of ^{137}Cs in the Northern Hemisphere[1] and with the 70 PBq release of ^{137}Cs estimated by Cambray et al.[3]. This amount of ^{137}Cs is about one-third of that estimated to be in the reactor core at the time of the accident and is about one-sixteenth of that released to date from all tests of nuclear weapons in the atmosphere.

The release from the stricken reactor took place in two distinct phases: the initial one on April 26, 1986, resulting from the initial accident and a second one several days later resulting from elevated temperatures within the remaining core[4]. Thus, the cloud of radioactive debris was very complex and did not follow a single path. Some regions in Eastern and Western Europe were impacted by significant deposition of fallout debris. For example, some locations in Bavaria actually

experienced a deposition of ^{137}Cs per unit area that was roughly 10 times higher than the average deposition from fallout from nuclear weapons testing in the atmosphere. At other locations, such as the United States of America and Canada, the deposition was still measurable, but of minor magnitude compared to global fallout from weapons testing.

The purpose of the work reported here was to estimate a collective dose commitment for the Northern Hemisphere. To do this, we combined the results for the USSR reported by the Soviets[4,5] with our own calculations.

3. METHODS

Our method of calculation is simple and direct and depends for input on simple measurements of either external exposure rate or the deposition per unit area of ^{131}I or ^{137}Cs. In order to apply this general method, it is necessary to know the relative radionuclide mixture at some point in time and to calculate the relative mixture at other points in time. To define our reference radionuclide mixture, we used the measured values reported for Nurmijarvi, Finland, for a mean collection time of 66 hours post accident[6]. Many other reported measurements indicate similar relative mixtures[1]. With the use of such a reference radionuclide mixture, the measurement of any one radionuclide is sufficient to infer the presence of the others.

The inference of deposition of radionuclides from a measurement of external gamma-exposure rate is only slightly more difficult. In this case, the relative radionuclide concentration must be weighted by its efficacy of producing an external gamma-exposure-rate field per unit deposition. For this calculation, we used the conversion factors (exposure rate per unit areal deposition) published by Beck[7]. Further details are provided in [1].

3.1 External Dose

Once the ground deposition of the radionuclide mixture is established, external exposure in air is calculated by projecting the resulting exposure rate into the future for 50 years. This is easily done by using the standard decay relationships for the reference radionuclide mixture and by allowing for the decrease in exposure rate due to weathering.

For rural environments, this weathering consists of vertical movement into the soil column. We used the standard concept that fallout radionuclides are distributed exponentially with depth[8]: short-lived (half life of less than 14 days) radionuclides with a relaxation depth of 0.16 g/cm^2, intermediate-lived (half life longer than 14 days, but less than 200 days) with 1.6 g/cm^2, and long-lived with a depth of 4.8 g/cm^2. The latter value is equivalent to an average depth of penetration of 3 cm, which is the standard value used by UNSCEAR for long-lived radionuclides[9].

For urban environments, horizontal movement occurs. Jacob[10] has reported that roughly half of the activity deposited within urban environments following the Chernobyl accident disappeared within a few days. We include this effect in our model with the assumption that half of the initially deposited material weathers with a half time of 7 days.

Additional factors are a conversion of 0.0087 Gy per R and 0.3 to convert from absorbed dose in air to organ dose including the effects of building shielding and occupancy. These same factors have been used by UNSCEAR[9], and are stated to be average values for the Northern Hemisphere. We have made the additional assumptions that 30% of each country's population lives in an urban environment where our urban runoff model applies and where building shielding and occupancy are expressed better by a factor of 0.15 to convert from dose in air to organ dose.

3.2 Internal Dose

The Chernobyl reactor accident happened at a time of transition from stored feed to pasture use for cows. Thus, it is appropriate to use a model that includes seasonal dependence of pasture use and growth and use of other crops such as fresh vegetables. For the calculations here, we used the PATHWAY model of Whicker and Kirchner[11] and their tabulated integrated intake values for an example exposure occurring on April 25 in the western USA. For this situation, radionuclide movement is calculated with the assumption that cows are not on pasture, but that they subsequently move onto pasture and/or derive about 20% of their dry matter intake from pasture or green chop beginning on May 1. This apparently corresponds to the actual situation in much of northern Europe at the time of the accident.

This model also incorporates a value of 0.39 m^2/kg for the normalized retention of fallout by vegetation. This value was measured for fallout deposited close to the Nevada Test Site under dry conditions and for relatively large particles. This value also appears to be appropriate numerically for Chernobyl fallout, which at farther distances consisted of smaller particles deposited primarily by rain[1].

The output of PATHWAY is integrated intake of a radionuclide per unit areal deposition. We then applied dose-conversion factors calculated by Ng[12], who used the ICRP methodology[13].

4. RESULTS

The results of our calculations combined with those reported by the Soviets for the USSR[4,5] are shown in Table I. The numbers in this table are the sums of the dose commitments via the external and the ingestion pathways. About half of the total dose commitment comes from the external exposure pathway; the radionuclide ^{137}Cs would contribute about two-thirds of the total from both pathways. We estimate that the total collective dose commitment for the first year following the accident was 630 000 person-Gy and that it will be 1 200 000 person-Gy over 50 years. Most of this will be experienced within the USSR and within the non-USSR part of Europe.

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Table I. Estimates of Collective and Average Individual Dose Commitment for Various Regions.

	Collective Dose Commitment (person-Gy)			
	1st Year		50 Year	
	Preferred Estimate	Average Individual Dose (mGy)	Preferred Estimate	Average Individual Dose (mGy)
USSR (European)	2.5E+05	3.3E+00	4.7E+05	6.1E+00
USSR (Asian)	5.9E+04		1.1E+05	
Europe (non-USSR)	3.1E+05	6.4E-01	5.8E+05	1.2E+00
Asia (non-USSR)	1.4E+04	7.6E-03	2.7E+04	1.4E-02
North America		2.4E-03		4.5E-03
United States	5.7E+02	2.4E-03	1.1E+03	4.6E-03
Canada	5.0E+01	2.1E-03	9.4E+01	3.9E-03
Northern Hemisphere	6.3E+05		1.2E+06	