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MEMORANDUM: Internal Dose Assessment for Rongerik Weather Unit, Operation CASTLE

This memorandum describes the method by which the internal dose from radiation exposure was determined for the Rongerik Weather Unit during Operation CASTLE in 1954. The unit consisted of twenty-eight Army and Air Force personnel stationed on Rongerik Atoll in the Marshall Islands. All men in the unit were exposed to radioactive fallout from Shot BRAVO of Operation CASTLE during the period 1-2 March 1954.

A. Background

Shot BRAVO was detonated on Bikini Atoll at 0645 hours (local time) on 1 March 1954. The total yield of the thermonuclear explosion was approximately 15-megatons TNT equivalent. The nuclear device was mounted on a barge in shallow water, about seven feet above the surface of a coral reef. The radioactive fallout from Shot BRAVO contaminated an area extending from about 20 statute miles upwind from Bikini to over 330 miles downwind and varying in width to over 60 miles. Included within the area of major contamination were Bikini Atoll and three downwind atolls: Ailinginae Atoll, Rongelap Atoll, and Rongerik Atoll.[1,2]

Twenty-eight American servicemen (25 Air Force personnel and 3 Army personnel) operated a weather station on Rongerik Atoll, about 150 miles east of Bikini. At approximately 1430 hours (almost 8 hours after the BRAVO detonation) the deposition of fallout on Rongerik was detected by a low-level gamma radiation monitoring instrument and subsequently observed visually. The Joint Task Force Headquarters was notified, and at 1500 hours the military personnel were instructed to wear long-sleeve shirts, long trousers, hats and GI shoes, but to continue the regular duty routine. At 2330 hours, a message was received to cease operations and move inside permanent buildings. At 1245 hours on 2 March 1954, eight men, the first eight men in alphabetical order on the detachment roster, were evacuated from Rongerik to Kwajalein Atoll by airplane; the remaining twenty men were evacuated by airplane at 1800 hours.[3]

Upon arrival at Kwajalein Atoll, the personnel evacuated from Rongerik were monitored for personal contamination and decontaminated. The decontamination program, consisting of repeated showers and radiation monitoring, continued from 2 March through 6 March. While at Kwajalein, the film badges that had originally been issued to the Rongerik detachment were collected and processed. In addition, urine samples, both pooled and individual, were collected and sent to laboratories in the United States for analysis. Late in April, the servicemen from Rongerik were transferred from Kwajalein to Tripler Army Hospital (Honolulu, Hawaii) for further observation and subsequent return to duty.[3,4]

B. Technical Approach

The technical approach used to estimate the organ-specific radiation dose commitments for the American military personnel exposed on Rongerik Atoll is based on the following data:

- Radionuclide inventory data for Shot BRAVO calculated by Lawrence Livermore National Laboratory.

- Urinalysis data for the exposed Americans obtained by Los Alamos National Laboratory.

The basic approach used to calculate the dose commitments has four steps.

- First, the calculated radionuclide inventory provides the time-dependent, relative activity of the radionuclides present in the fallout.

- Second, the inventory is normalized to the actual activity intake by relying on post-shot urinalysis data to determine the amount of I-131 activity intake.

- Third, dose conversion factors (rem per unit activity inhaled or ingested) are determined for the principal modes of radionuclide intake.

- Fourth, organ-specific dose commitments (rem) are calculated by combining the normalized activity inventory data with the dose conversion factors.

A description of each of the above steps is provided in the subsections below.

(1) Relative Activity

The basic fallout radiological data calculated for Shot BRAVO was provided by Lawrence Livermore National Laboratory (LLNL).[5] The calculations were performed using the isotope generation and depletion code ORIGEN.[6] Modifications to the ORIGEN-calculated results were made based on radiation chemistry data for BRAVO available to LLNL. The LLNL-calculated data for BRAVO thus reflect the device-specific characteristics (such as fissile nuclides, neutron energy, and light/heavy element production) that are necessary to correctly specify the radionuclide content of the fallout material. The radiological data set for the radionuclide mixture is unfractionated; this leads to high-sided internal dose commitments for most organs.

(2) Inventory Normalization

Urine samples were collected from the exposed American servicemen and sent to U.S. laboratories for analysis. These afford the opportunity for a more accurate dose calculation than possible from first-principle physical considerations. On site radiation surveys were late (D+9 days) and did not facilitate an internal exposure analysis.[7] The urinalysis data collected by Dr. Payne S. Harris of the Los Alamos National Laboratory are the most useful for this dose calculation because they are based on a comparatively early (D+17 days) sample collection and are well documented.[8] The urinalysis results reported by the Naval Radiological Defense Laboratory involved samples collected much later (D+44 days and after), for which the available documentation is weak.[9] It is understood that urinalysis results were also reported by medical personnel at Tripler Army Hospital; however, apparently the sample collection times were so late that meaningful results were not reported.[4]

The urinalysis data reported by Dr. Harris for the American servicemen were based on a 10-man, pooled urine sample collected on 18 March 1954. The urine samples were analyzed for plutonium, calcium-45, strontium-89, ruthenium-103, iodine-131, and barium-140. The I-131 analysis of the pooled urine sample provided the basis for limited internal dose estimation by Dr. Harris; the iodine data have been used for the present dose calculations. Dr. Harris judged that the I-131 analysis was the most accurate; it also led to the highest doses.[8]

The basic result of the I-131 analysis of the pooled urine sample was the determination that, for a "nominal" individual, the amount of I-131 excreted in urine over a 24-hour period at the time of urine sample collection (D+17 days) was 4.0 nanocuries. That result is used to determine the amount of I-131 intake.

The amount of a radionuclide available for excretion is related to the amount and decay rates of the radionuclide and its parent radionuclides initially inhaled and ingested. Where, as in the case of I-131, the contribution from decay of parent radionuclides within the body is negligible, the excretion may be expressed as follows:

$$A_u(t) = Q_I \cdot f_1 \cdot Y(t) \cdot F_u$$

where

$A_u(t)$ = the amount (μCi) of the radionuclide in a 24-hour urine sample taken at time t,

Q_I = the amount (μCi) of the radionuclide intake,

f_1 = the fractional amount of the radionuclide intake that is transferred to the blood,

$Y(t)$ = the ratio of the amount (μCi) of the radionuclide excreted with a 24-hour period to the amount (μCi) of the radionuclide uptaken by the blood, and

F_u = the fraction of the total daily excretion that is present in the urine.

As mentioned above, the value of A_u (D+17) is 4.0 nCi or 0.004 μCi for I-131. For iodine, the biological parameters f_1 and F_u are both equal to 1.0.[10] Equations for the fractional daily excretion of I-131, Y(t), are available for several retention models.[10,11,12] The value of Y(D+17) depends on the retention model used and, rather weakly, on the assumption of instantaneous or continuous (over 24 hours) intake. Based on the continuous intake mode and the most recent retention model (Reference 12), Y(D+17) = 0.000298 μCi/day per μCi uptake. For these values of the parameters, the amount of the I-131 intake, Q_I, is 13.4 μCi. This value of Q_I is used to normalize the radionuclide inventory, based on the effective time after fission of the intake. As discussed below, this is about H+10 or 11 hours.

(3) Pathways Dose Conversion Factors

The relationships between I-131 and other radionuclide levels in the body depend on the mode of intake, metabolism, and radiological decay. These are incorporated into the published dose conversion factors. Both inhalation[4] and ingestion[8] have been proposed as pathways leading to internal dose for Rongerik servicemen. The only pathways significant enough to lead to the measured I-131 levels were direct inhalation of descending fallout and ingestion of contaminated food or water. Despite the proper storage of the servicemen's foodstuffs, contamination of served food would have occurred during mealtime; the screened mess area did not prevent the infiltration of descending fallout.[3] Both pathways are thus associated with the approximately H+3 to H+13 hour interval during which most fallout occurred on Rongerik.

Inhalation and ingestion dose conversion factors are considerably different for many radionuclides; absorption of many substances into the blood is dissimilar in the respiratory system versus the GI tract. However, the size of the inhaled particles affects this distinction. Analysis of soil samples on Rongerik indicated that most of the radioactivity in the soil was associated with particles in the size range of 60 to 200 μm diameter.[9] Because particles in this size range do not form suspensions in air, they have been disregarded in published compendia of inhalation dose conversion factors. The transient exposure to descending fallout is an exceptional circumstance involving inhalation of large particles.

Large-particle inhalation dose conversion factors are derivable using the simplifying condition that, for particles greater than 10 μm diameter, all of the inhaled material is initially deposited in the nasopharyngeal region of the respiratory tract.[13] This material is removed by chemical (absorption) and mechanical processes, and goes either to the blood, with subsequent transfer to other body organs, or to the gastrointestinal (GI) tract, with subsequent transfer to the blood and further transfer to other body organs or bodily elimination by excretion. The "pulmonary clearance classification" of the inhaled material (roughly analogous to the solubility of the material) determines the amount of the material that is initially transferred to the blood or the GI tract; for example, 99 percent of an "insoluble" material will go to the GI tract with only 1 percent going to the blood, whereas a "very soluble" material will be divided evenly between the GI tract and the blood.[12]

Since ingestion plays a major role in the fate of an inhaled large particle, inhalation dose conversion factors for large particles follow from modification of ingestion dose conversion factors. This modification is necessary to properly account for that portion of the inhaled material that is initially transferred to the blood, rather than to the GI tract. The metabolic data needed to construct these dose conversion factors are given in ORNL/NUREG/TM-190[12] for the most radiologically significant radionuclides. The TM-190 dose conversion factors, based on the most current dosimetry information, are used in conjunction with these. For those radionuclides not addressed in TM-190, unmodified ingestion dose conversion factors are taken from NUREG-0172.[14]

The differences between ingestion and large-particle inhalation dose conversion factors can be minor. For example, radionuclides poorly absorbed in the nasopharyngeal region may subsequently irradiate the GI tract similarly to those ingested. Such radionuclides tend to dominate internal dose to the GI tract. Some substances, such as iodine, are almost completely absorbed after either mode of intake. Thus, the radionuclide inventory is unambiguously determined from I-131 without consideration of the relative magnitudes of ingestion and large-particle inhalation.

(4) Organ-Specific Dose Commitments

The 50-year dose commitment to organ j, D_j, resulting from the intake of a mixture of radionuclides is given by

$$D_j = \sum_i Q_I^i \cdot DCF_i^j.$$

Q_I^i, the amount of intake of radionuclide i, is determined from the radionuclide inventory as normalized by the I-131 activity intake developed from the urinalysis data. The dose conversion factor, DCF_i^j, is for organ j due to the intake of radionuclide i.

C. Results

The 50-year dose commitments resulting from the inhalation and ingestion of fallout radionuclides were calculated for the following organs: thyroid, lower large intestine (LLI) wall, liver, kidney, bone, pancreas, testes, and lung. For these dose calculations it was assumed that the intake of radioactive material was at a constant rate (on a mass per unit time basis) for the duration of fallout deposition (H+8 to H+13). The calculated thyroid dose commitment of 170 rem and LLI wall dose commitment of 75 rem are considerably higher than the dose commitments for the other organs, which are about 0.1 to 1 rem. These values are essentially independent of the relative magnitude of the inhalation and ingestion pathways. Only the thyroid and LLI wall dose commitments are meaningful increments to the external, whole-body dose that is roughly applicable to each organ.

The radioisotopes of iodine account for virtually all of the thyroid dose commitment; however, more than 10 percent results from tellurium isotopes that decay to iodine within the body and then are translocated to the thyroid. For the LLI wall dose commitment, about one-half is attributed to the uranium and neptunium radionuclides, and about one-quarter is attributed to the radioisotopes of yttrium and zirconium; other fission products contribute the remainder.

Ordinarily, caution would be advised in basing internal doses to specific individuals on a pooled urine sample. However, significant metabolic differences among individuals are less likely when, as on Rongerik, all personnel were healthy young adults with similar diet. Dr. Harris has claimed (documentation unavailable) that a limited sampling of individual urines of Rongerik personnel showed deviations from the I-131 level of the pooled sample of no more than 40 percent. This value also reflects any variations in the details of exposure among the servicemen.

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