Plutonium Dose Assessment Using Blood Samples†

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Urine bioassay is a standard method for assessing plutonium uptake, but is it the most viable method? Since the plutonium in urine has been eliminated from systemic blood, blood is herein investigated as a suitable medium for plutonium bioassay.

The obvious issues are the amount of plutonium in a practicable blood sample, compared to that in a 24-h urine sample, and the interpretation of body burden and organ dose from that amount. The relative concentration of plutonium in blood and urine is dependent on the elimination rate (daily fraction) from blood to urine. Because some of the current biokinetic modeling incorporates intermediate compartments between the blood and the urine, translocation rate constants (TRC) must be compared carefully. The recent recommended TRC of the plutonium from blood directly to urine (bladder content) is 0.0129 d^{-1} in Publication 67 of the International Commission on Radiological Protection (ICRP 1993). For tissues in the urinary path, the TRCs are 0.00647 d^{-1} from blood to the kidneys and 0.01386 d^{-1} from the kidneys to the bladder content. Further, "to account for an apparent increase with time in fractional clearance of circulating plutonium," the applicable TRCs in Publication 67 are 0.0806 d^{-1} from blood to soft tissues and 0.000475 d^{-1} from soft tissues directly to the urine. The net implication at several years after plutonium uptake, when the level of plutonium in the blood approaches a dynamic equilibrium, is that the plutonium eliminated in 24-h urine is almost 6 percent as much as the total plutonium in blood — an effective TRC of 0.06 d^{-1}. This contrasts to the findings of (1) Hickman *et al.* (1995), who reported based on excretion data from seven exposed plutonium workers a TRC (effective) of 0.0078 d^{-1} from blood to urine; (2) Thomas et al. (1984), who reported based on animal and human data a TRC of 0.008 d^{-1} of plutonium from blood to urinary excretion; (3) Ohlenschlaeger *et al.* (1984), whose 24-h urine and autopsied blood samples from a single exposed plutonium worker imply an effective TRC from blood to urine of 0.003 d^{-1}; and (4) Sun (1987), who obtained a TRC of 0.009 d^{-1} for plutonium from blood to urinary excretion (with modeled direct elimination only), based on a four-compartment mammalian model and together with Leggett's plutonium systemic whole-body retention function (Leggett 1984; Leggett 1985).

The above information implies that plutonium is more concentrated in blood than in urine and, based on the non-ICRP references, much more concentrated. Since plutonium behaves in a similar fashion as iron in blood, it bonds with transferrin and is carried by blood cells circulating in the body (Durbin 1972; ICRP 1986) — effectively in a uniformly mixed pool. Therefore, the accuracy and reliability of plutonium dose assessment using blood sampling are expected to be better than with urinalysis methods. Analysis of blood samples is also recommended for finding the solubility of a plutonium contaminant and the dynamic properties from the site of entry to the systemic organs (Clemente and Delle Site 1982). A blood bioassay program can be used either in coordination with, or as a replacement for, using timed (non 24-h) urine samples to reduce

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uncertainties in uptake or dose. A blood bioassay program is also useful for investigating the placental transfer of plutonium between maternal blood and the conceptus.

The necessary blood sample volume is estimated as follows. The total weight of blood is about 7.7% of the total body weight (Langham *et al.* 1980; Voelz *et al.* 1979). The suggested average blood weights in a male adult and a female adult are 5,900 and 4,100 g, respectively (Williams and Leggett 1989). The density, ρ, of blood (ranging from 1.048 to 1.066) is similar to that of the body overall. Based on all above non-ICRP suggested TRC information, the urinary elimination of plutonium within a 24-h interval equates to the amount of plutonium contained in between 20 and 50 ml of blood for a male adult. In other words, for blood bioassay, a small sample volume of blood is sufficient for monitoring plutonium uptake and assessing dose whenever urine bioassay is viable. However, the blood sample volume actually required will depend on the sensitivity of the measurement method to be used, the level of plutonium contamination in the body, and the time after exposure.

The value(s) of TRC chosen for analysis is not as significant for determining a blood sample volume to match the plutonium content of a urine sample, as it is in determining the body burden and organ doses. It is preferable that TRCs, systemic retention functions, and dose conversion factors be derived from the same metabolic model. However, that does not imply that a self-consistent set (e.g., ICRP) of parameters currently provides the best representation of available data for bioassay applications.

Let A(t) be the plutonium content [Bq] at the collection time t [days] after an acute uptake in a volume V [ml] of blood for a person of weight W [g]. Then, the committed effective dose equivalent (CEDE) can be calculated for an adult using the following equation:

$$CEDE[mSv] = 1\ mSv\ Bq^{-1}(0.077*W*\rho^{-1}*V^{-1})(A(t)B^{-1}(t)),$$

where the 1 mSv Bq^{-1} is a plutonium dose conversion factor derived from ICRP Publication 56 (1990) for adults; 0.077*W and ρ*V are the total blood weights [g] of the body and sample, respectively. The B(t) is a time-dependent plutonium retention function in the total blood and can be used to solve for the fraction of plutonium retained in the systemic blood at any time t. An adequate B(t) is necessary to interpret blood sample results. There are several plutonium B(t) available in the literature (Healy 1957; Durbin 1972; Leggett 1985; Leggett and Eckerman 1987; and Sun 1987). For example, based on Leggett's plutonium systemic retention function, the following B(t) is a four-exponential-term function reported by Sun (1987):

$$B(t) = 0.9216e^{-0.693t} + 0.07275e^{-0.03t} + 0.004275e^{-0.0028t} + 0.001385e^{-0.0000216t}.$$

When 24-h urine sample collection protocols are used, expensive measures over a 24-h period must be taken to ensure the integrity and quality of the sample (Sun *et al.* 1993). For a 24-h urine equivalent sensitivity, only a small blood sample is required whereas one pint (about 500 ml) is extracted during a normal blood donation. With a qualified nurse, obtaining a small blood sample is easy, fast, simple, and safe. This method ensures no external sample contamination and reduces the overall cost of sample collection, relative to urine. Thus, it is expected that blood bio-assay for plutonium will prove viable for many applications in lieu of or along with urine bioassay.

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