NUCLEAR REGULATORY COMMISSION RADIATION ABSORBED DOSE RECONSTRUCTION FOR FAMILY MEMBER OF I-131 PATIENT

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Running Title: NRC dose calculation from I-131 patient

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Abstract: A terminally ill patient with metastatic thyroid cancer and severe renal insufficiency was treated as an inpatient with 10,545 MBq (285 mCi) $Na^{131}I$. The patient died six days after radiopharmaceutical administration while still in the hospital. A close relative of the patient disregarded the instructions of the Radiation Safety Officer (RSO) and insisted upon staying close to the patient for long periods of time until the patient's death. The licensee later reported to the Nuclear Regulatory Commission (NRC) that this member of the public had likely received a dose in excess of the 1 mSv (100 mrem) regulatory limit. The NRC subsequently performed a dose reconstruction and determined that the family member received an exposure of 15 cSv (rem) total effective dose equivalent (TEDE). An analysis of the NRC's approach and an alternative dose reconstruction, in which the TEDE was determined to be approximately a factor of as much as 17 lower, is presented.

Key Words: Nuclear Regulatory Commission; radiation dose calculation

Case Presentation: A patient with terminal metastatic thyroid cancer and severe renal insufficiency was treated with 10,545 MBq (285 mCi) $Na^{131}I$ and hospitalized in accordance with NRC requirements pursuant to 10 CFR

Part 35.75. The patient died six days after radiopharmaceutical administration while still in the hospital. The RSO measured radiation levels in the patient's room each day, both at 1 meter from the patient and at the patient's bedside. The initial dose rate measurements following radiopharmaceutical administration were 0.040 cSv/h (rem/h) and 0.400 cSv/h (rem/h) at 1 meter and at the bedside, respectively. According to the NRC, these radiation levels diminished with an effective half-time of 3 to 4 days.

A close adult relative of the patient disregarded the instructions of the RSO and insisted upon staying close to the patient for long periods of time until the patient's death. The relative was reminded by licensee staff, including the RSO, to take a position behind a bedside shield. As a result of the relative's proximity to the patient and the amount of time spent in areas of elevated radiation levels, the licensee later reported to the NRC that the relative likely received a dose in excess of the 1 mSv (100 mrem) regulatory limit.

The NRC subsequently performed a dose reconstruction using the RSO's measured dose rate values at the bedside and the daily stay times for the

relative that were determined from interviews with the relative and licensee staff. Details of this analysis are publicly available in NRC's AgencyWide Documents Access and Management System (ADAMS), accession number ML023440102. The NRC assumed that the relative was at the bedside position for the total amount of stay time each day. NRC determined TEDE by multiplying the measured dose rates by the estimated stay times. The dose rates, stay times, estimated TEDE during each day, and the total TEDE are presented in Table 1. As shown in the Table, the TEDE was estimated to be 15 cSv (rem) for the relative. Only the external dose component was considered; no mention is made concerning the possibility or likelihood of internal intake. Therefore the TEDE is equal to the deep dose equivalent (DDE).

SNM/ACNP Concern Over NRC Dose Reconstruction: The Society of Nuclear Medicine (SNM) and the American College of Nuclear Physicians (ACNP) were concerned that NRC's dose reconstruction in this case might be overly conservative. Meetings with NRC Commissioners McGaffigan and Merrifield were held to discuss NRC dose reconstructions as well as to suggest the formation of an independent committee composed of experts from the SNM/ACNP and other dosimetry experts to conduct peer reviews

of NRC's dose calculations. On September 9, 2003, NRC Chairman Diaz sent a letter to Henry Royal, M.D., President of the SNM, making the following statements of interest:

(1). "In this particular case, the hospital had performed daily dose rate measurements at the bedside. The NRC estimated the stay times next to the bed based on interviews with the [relative] and the hospital staff. The dose to the [relative] was then calculated using these stay times and the measured exposure rate for each day. Since the NRC staff was able to use measured dose rates and did not have to perform a complex dose reconstruction analysis, the Commission does not feel that the staff's results were overly conservative."

(2). "While we appreciate your offer to have an independent SNM/ACNP Committee review our calculations, we believe the staff gets sufficient support from its existing medical and scientific consultants, contractors, and the ACMUI [Advisory Committee on Medical Uses of Isotopes] in performing and reviewing its dose reconstructions."

(3). "The staff will also continue to evaluate the state-of-the-art in dose reconstruction in order to keep its determinations as realistic as possible."

The NRC thus maintains that its dose reconstruction in this case is accurate, and states that its methods are not overly conservative and are essentially "state-of-the-art". However, the authors present below an alternative dose reconstruction based on the same dose rate and stay time data.

Alternative Dose Reconstruction: The initial dose rate measurement at 1 meter from the patient was 0.040 cSv/h (rem/h). The reasonableness of this measurement can be ascertained by theoretical calculation, according to:

Dose rate at 1 meter (cSv/h) = Γ x A_0 x SF

where Γ = specific gamma ray constant for ^{131}I at 1 m (= 5.95E-6 cSv-m^2/MBq-h); A_0 =10,545 MBq; and SF = shielding factor due to patient attenuation. For ^{131}I this has been reported to be 0.6 (*1*).

Thus, dose rate at 1 meter = (5.95E-6)(10,545)(0.6) = 0.038 cSv/h.

According to this theoretical calculation, the 0.040 cSv/h measurement at 1 meter is therefore realistic and reasonable. (Note: This simple calculation illustrates that even if no dose rate measurements had been obtained, no "complex dose reconstruction analysis" would have been needed.)

No such theoretical calculation can be used to directly verify the initial 0.400 cSv/h dose rate measurement at the patient's bedside since no distance was given. The NRC did not attempt to estimate this distance and apparently assumed that the relative's location corresponded to dose rate levels measured at the patient's bedside. "Bedside" is imprecise and not a standard unit of length. We believe that it is imperative to **reconstruct the distance before you reconstruct the dose.** The initial measured dose rate at 1 m can be used to estimate the distance at which the bedside dose rate measurements were taken. Using the inverse square law, $(40/400)^{1/2}$, the bedside dose rate is estimated to be at a distance of 31.6 cm from the patient. Since this initial dose rate measurement was performed at a time when the activity was mainly confined to the stomach, a point source assumption and use of inverse square is an adequate approximation. Does 31.6 cm realistically represent the distance between the relative and the

patient? If not, the bedside dose rate measurements can not be used to estimate the relative's exposure.

From the NRC's dose reconstruction in the ADAMS document, it is reported that the relative's closest position to the patient was sitting against the bed, with elbows or forearms on the bed. The NRC approach to dose calculation is precisely defined in 10 CFR Part 20. Pursuant to 10 CFR 20.1003, arms distal to the elbow and legs distal to the knee, as well as hands, elbows, feet, and knees, are extremities; doses to extremities are reported as shallow-dose equivalents. For purposes of external exposure, head, trunk, and arms and legs proximal to elbow and knee, respectively, are considered "whole body parts" for which DDEs are calculated. Since TEDE in this case is equivalent to DDE, and pursuant to 10 CFR 20.1201(c) the assigned DDE must be for the part of the body receiving the highest exposure, we first assumed that the patient's proximal arms were at the closest distance to the patient and therefore received the highest exposure. It is reasonable to assume that this patient-to-relative's proximal arm distance could be on the order of 31.6 cm. If the patient's proximal arms remained in this position for the entire stay times, then the bedside dose rates used by NRC to estimate TEDE is a reasonable approach.

It is, however, likely that the relative's body, including proximal arms, was at a further distance for some of the time, due to comfort considerations from prolonged stay times. For example, it is likely that the relative sat back in the chair at least part of the time, instead of being continually hunched forward over the bed. It is not unlikely that this comfort distance could be comparable to 1 meter, while still being "at bedside". It is therefore realistic to assume that the relative's closest distance was at an average "bedside" distance between 31.6 cm and 100 cm, i.e., an average distance of 65.8 cm. That is, the proximal forearm averaged a distance of 65.8 cm from the patient. **In this case, the NRC dose estimate is overly conservative by a factor of $(65.8/31.6)^2 = 4.3$.**

Up to now, we have used NRC regulatory definitions and criteria for the TEDE calculation. TEDE can also be determined in this case for the relative's trunk as the surrogate for "whole body" TEDE. While this approach is not specifically addressed in NRC regulations, we believe it would be prudent to determine this additional dose estimate, especially in this case since the proximal arms and trunk of the body were at significantly different distances from the patient. Thus, if TEDE values are to be used in

a risk assessment, it may be important to differentiate the estimated dose values for the individual's arms from that of the trunk.

Simulated measurements of the patient-relative geometry performed independently by the authors yielded a center-of-gravity to center-of-gravity (umbilicus-to-umbilicus) distance of 65-70 cm. On average, the umbilicus-to-umbilicus distance was therefore between 65 cm and 100 cm, for an average distance of 82.5 cm. **Using this scenario, the NRC dose estimate is overly conservative by a factor of $(82.5/31.6)^2 = 6.8$ using the relative's trunk as the "whole body" part of interest.**

Another important factor to consider is attenuation by the exposed individual's body. The NRC has taken into account the shielding by the patient's body by using a measurement instead of using the specific gamma ray constant for an unshielded point source. However, NRC did not take into account the shielding (i.e., attenuation) by the body of the family member, which requires essentially the same shielding factor as that which applies to the patient. TEDE is not equivalent to dose rate multiplied by time; attenuation by the exposed individual must be taken into account. For ^{131}I, the shielding factor is 0.6 for the patient, as previously discussed (*1*),

and also 0.6 for the family member's body (*2*). The attenuation factor for the DDE according to NRC regulation, however, is different. According to 10 CFR 20.1003, the DDE, "...which applies to whole body exposure, is the dose equivalent at a tissue depth of 1 cm...". Using the linear attenuation coefficient for ^{131}I in tissue-equivalent material (*4*), and a depth of 1 cm, the corresponding attenuation factor for the DDE is $e^{-(0.11)(1)} = 0.9$. **Thus, the NRC overestimated the relative's TEDE, based on its own regulatory criteria, by an additional factor of 1/0.9 = 1.1 based on use of the proximal arm. The TEDE overestimate is 1/0.6 = 1.7 based on the use of the trunk of the body.**

The NRC's dose reconstruction also did not take several other important factors into account. The NRC assumed that the exposure rate at one point in time measured by the RSO was constant for 24 hours, instead of exponentially decreasing. While it is reasonable to ignore decay if the effective half-time is long, in this case it was only 3.1 days based on the time-bedside dose rate data. In addition, there is an obvious mistake in the dose rate on Day 4, which cannot be the same as it was on Day 3 (see Table 1). Finally, at times shortly after dose administration, this patient is not really a point source, but more closely resembles a line source (*3*). This is

especially important at short distances from the patient, since it decreases the exposure relative to that which is calculated using the inverse square law. These three considerations taken together potentially represent an additional NRC dose overestimate by a factor of 1.5.

Thus, the NRC's dose calculation is conservative by a factor of only (1)(1.1)(1.5) = 1.6 using the proximal arms as the body part receiving the highest exposure under the assumption that the proximal arms are always at a distance of 31.6 cm from the patient. If the proximal arms are at an average distance of 65.8 cm, the NRC calculation is conservative by a factor of (4.3)(1.1)(1.5) = 7.1. If umbilicus-to-umbilicus calculations are used, the NRC dose calculation is potentially overly conservative by a factor on the order of (6.8)(1.7)(1.5) =17. The relative's TEDE may well be a maximum of only 0.9 cSv if umbilicus-to-umbilicus calculations are used.

Discussion/Conclusion: A specific dose reconstruction performed by The NRC has been reported. An analysis of the NRC's dose reconstruction methods indicates a potential dose estimate that is overly conservative by a factor of approximately 1.6, 7.1, or 17, depending upon calculation methods

and assumptions. NRC regulations require that the TEDE calculated be for the body part receiving the highest exposure. Nothing in the regulations, however, precludes use of other body parts for the TEDE calculation. We believe that the factor of 17 realistically applies to the true whole body dose in this case, while the factors of 1.6 and 7.1 more accurately reflect the proximal arm dose. If a dose estimate is to be used to determine risk, as was done by the NRC in this case, then we recommend use of not only the regulatory-mandated TEDE value but also the most appropriate TEDE value based on the specific circumstances.

We recognize that "state-of-the-art" dose reconstruction should result in a probability distribution rather than a single dose estimate. The uncertainty for each parameter in the calculation should be modeled and Monte Carlo simulation could then be used to get a frequency distribution of the likely dose. This, however, is beyond the scope of this case report.

All licensees should expect that the NRC performs dose calculations using state-of-the-art dosimetry methods that result in realistic and not overly conservative dose estimates. This is especially important since these dose estimates are used for risk assessment. The large discrepancy in

methodology, criteria used, and estimated dose demonstrated in this case raises important issues. We therefore recommend that the Commissioners consider a case-by-case review of staff dose calculations by an outside expert panel to gain valuable perspectives and alternative calculation strategies.

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TABLE 1. Bedside dose rates, stay times, and NRC TEDE calculations.

Day	Dose rate at bedside (cSv/h or rem/h)	Stay time (h)	TEDE (cSv or rem)
0	0.400	0	0
1	0.348	6	2.088
2	0.250	12	3.000
3	0.210	12	2.520
4 (through 5 PM)	0.210	8.5	1.785
4 (5 PM - midnight)	0.210	7	1.470
5	0.132	20.5	2.706
6	0.107	11.5	1.231
		Total	14.800

ATTACHMENT D

ADVISORY COMMITTEE ON THE MEDICAL USE OF ISOTOPES

CHARTER FOR THE SUBCOMMITTEE TO REVIEW THE DOSE RECONSTRUCTIONS

Formation of ACMUI Dose Evaluation Subcommittee

On January 29, 2004, Thomas Essig, ACMUI Designated Federal Official, sent an e-mail message to the ACMUI caused the formation of a Dose Evaluation Subcommittee. Details of the Subcommittee's function is as follows.

Purpose: A Dose Evaluation Subcommittee has been formed to enable the full Committee to provide its advice to the NRC staff regarding a dose reconstruction for the daughter of a patient who had received a radiation exposure in excess of the public dose limit while comforting her dying mother who was undergoing radioiodine therapy at the St. Joseph Mercy Hospital in Ann Arbor, Michigan.

Subcommittee membership:

Dr. Leon Malmud, Chair. Will oversee the Subcommittee and ensure that product delivery schedule is met, including vetting of the Subcommittee's product with the full ACMUI.

Dr. Jeffrey Williamson, Member. Will evaluate the technical details of the dose evaluation, with an eye toward assessing the reasonableness of the 15 rem dose estimate.

Dr. Douglas Eggli, Member. Will provide insights from his perspective as a nuclear medicine physician.

Ms. Sally Schwarz, Member. Will provide radiopharmeceutical insights, as appropriate.

Ms. Nicki Hobson, Member. Will provide patient advocate insights, as appropriate.

Approach: The attached inspection report prepared by NRC Region III contains an assessment of the dose received by the daughter while comforting her mother during her final days. The Dose Evaluation Subcommittee is requested to prepare independent views of the evaluation of radiation exposure received by the daughter. Input data are contained in the attached file. The Subcommittee is specifically requested to evaluate the approach to the dose reconstruction taken by the NRC Region, as well as the critique of the inspection report prepared by Drs. Carol Marcus and Jeffry Siegel (this critique is not available electronically and will be faxed to you). In preparing its report, the Subcommittee should indicate, for each aspect of the dose reconstruction and the Marcus/Siegel critique, whether it agrees or not with the evaluations and representations presented and why.