

ACMUI Dose Reconstruction Subcommittee (DRS)
Appendix B: Technical Report
15 April 2004

Interview of Region III Inspectors by DRS members

- DRS interviewed Mr. Cameron and Mr. Wiederman (C&W) from Region III, who performed St. Joseph's Hospital inspection
- Additional information gleaned
 - Licensee found minimal or no contamination in patient room
 - C&W provided times/dates of bedside and "1 m from bedside" measurements performed by licensee. However, exit and entry times of the daughter are not available.
 - C&W reported that a urine collection bag, placed near the patient bed, contained a significant radiation burden. During part of the daughter's exposure, this bag may have been separately shielded. DRS did not include the urine bag as an additional radiation burden, but assumed that it was included in the Licensee's bedside and 1 m dose measurements.
 - C&W stated they interviewed daughter for about 90 minutes: pertinent findings
 - Daughter did indeed "move around": bathed, fed and provided other basic care to patient. However, daughter insists she sat in the position assumed by the Region III calculations.
 - Daughter sat in chair facing the bed and patient's left side. Daughter's knees were placed against lowered bed rail and sat leaning forward with her elbows on edge of mattress.
 - C&W stated that licensee personnel performed bedside measurements at the point where they believed daughter's forearms were positioned
 - C&W had the impression that daughter was so attached to her mother (the patient), that using the "general rationale person model," a person who seeks to minimize discomfort, would not yield a good approximation to the daughter's time-space distribution around the patient.
 - Nursing notes are insufficient to provide definitive factual confirmation of the daughter's dwell times or distance assumptions
 - C&W believed that sometimes the daughter was closer than the stated distance and sometimes further. Also, the daughter was exposed by a urine reservoir, which was not otherwise included in the calculations. Hence they still believe that their assumption is a reasonable average.
- The DRS achieved consensus on the following issues:
 - C&W beliefs notwithstanding, that the daughter could have sat rigidly in a single position for so long still seems implausible.
 - C&W were unable to provide any factual basis for assuming other average distances or non-unity occupancy factor.
 - DRS is not aware of any industry guidance or scientific studies (e.g., time motion studies) which are applicable to this case and could provide the basis for an alternative set of time-distance assumptions.

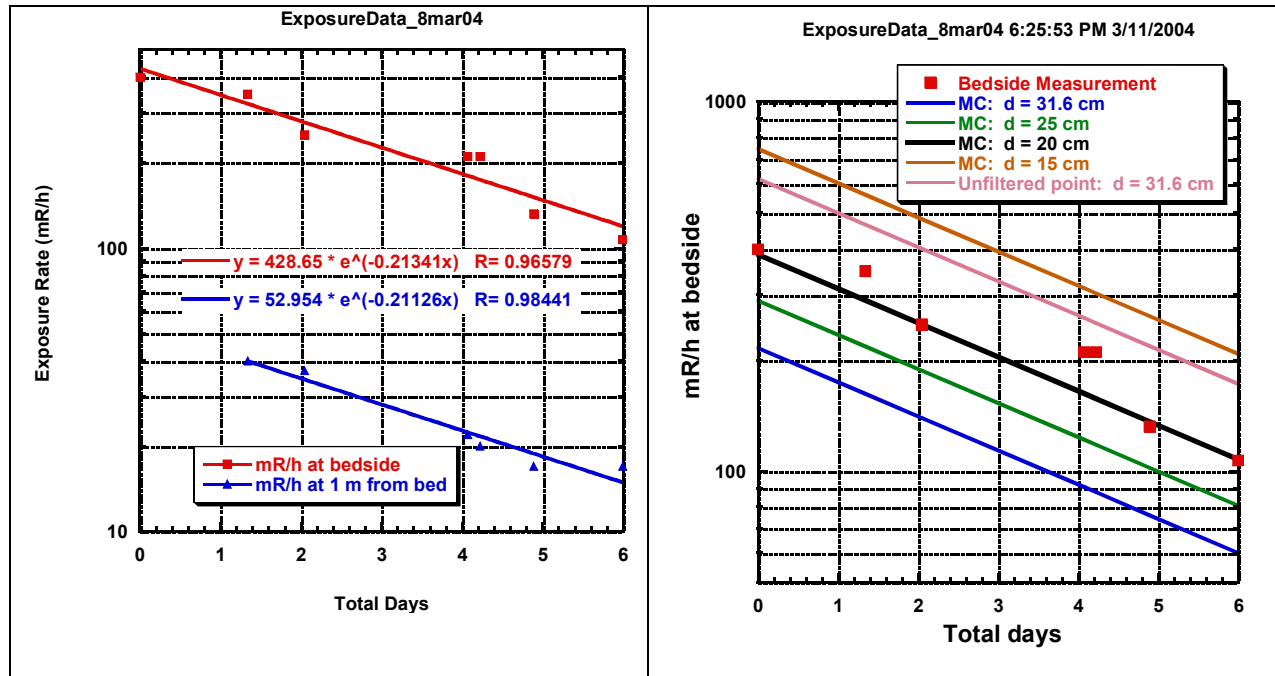
- Data available from this interview do not permit quantitative assessment of dose estimation uncertainty due to dwell time and distance uncertainties.
- Given the data available to inspectors and lacking an objective basis for constructing plausible alternative scenarios factual basis, their assumptions seemed reasonable.

Interview of Ralph Lieto on 3/12/04 and review of SJH written materials

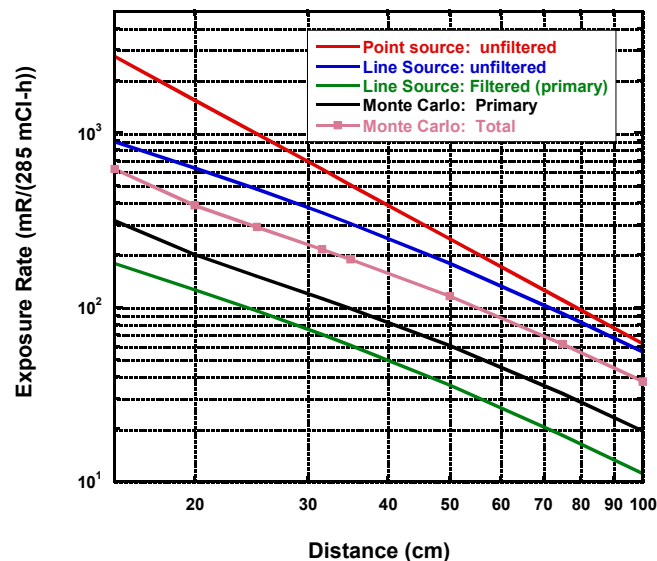
- Interview with Ralph Lieto (by J. Williamson) yields following findings
 - SJH continues to contest NRC dose reconstruction. They believe that NRC has willfully ignored their far more intensive reconstruction efforts. The crux of the dispute is how long the daughter was positioned near the patient without the use of portable shields.
 - Based on recollections of two eye witnesses to J. Cameron interview of daughter, ~~Mr. Lieto~~ [the licensee](#) claims
 - Interview was superficial and lasted only 15 minutes
 - JC “led” patient on” by asking questions such as “were you positioned like this?” rather than asking her “tell me what happened in your own words”
 - Contradictions between this brief interview and more extensive multiple witness interviews were ignored by NRC.
- Other findings
 - During 7/2, 7/3 and 7/4 up until 7/5 3 PM, licensee maintains that bedside shields were in place and that daughter followed instructions to stay behind them. Region III claims that shields were not being used or positioned properly. No licensee documentation exists to dispute Region III daughter dwell times.
 - Shields were 1” thick, 36” wide and 46.5” tall providing 24 inches vertically of protection. Shields could be positioned such that shield surface was in contact with mattress edge.
 - Licensee information based on detailed staff interviews conducted two weeks after incident and daughter telephone interview conducted in Sept 2002.
 - To what extent shields were used after 7/5 is contradictory: Licensee interview summary is contradictory and daughter claims in 9/02 interview that they were not used after 7/5 but were used before.

Technical Issues

Effective half life and Reconstructed distance of bedside readings



The more complete data consistently reveal $\lambda = 0.212 \text{ da}^{-1}$, equivalent to a half-life of 3.26 days. Based on Monte Carlo simulations, the patient-to-detector center distance best accounting for the measurements is about 20 cm. This suggests readings were taken with detector a few cm from lateral surface of the patient. Monte Carlo simulation is warranted in this particular case because the patient was known to have impaired renal function and because the fraction of thyroid uptake is typically small in metastatic thyroid cancer patients. This assumptions warrants treating the patient as a cylindrical volume source in which radioactivity is uniformly distributed.



Since a typical hospital bed is about 37 inches wide, the mattress edge-to-patient center is about 47 cm. Assuming that the daughter placed her forearms on the lateral aspect of the mattress edge, a distance of 37 cm would seem to be the shortest distance between the daughter's forearms and the patient center that could be maintained for a long period of time. Hence, DRS suggests that 37 cm is a more appropriate distance to apply to the Region III scenario rather than the estimated 20 cm measurement distance. Based on the ratio of MC air-kerma rates at 35 cm and 20 cm, it is reasonable to scale the beside readings downward by a 0.65 factor.

Continuous vs. Stepwise decay.

Region III simply multiplied the patient dwell time by the measured beside reading without correcting for decay either during the interval between the measurement time and beginning of the daughter's exposure, or during the interval of exposure. Let t = time between measurement and start of daughter's exposure of duration t . Then

$t = 0$ and $T = 21$ hr implies Region III/True exposure = 1.09 (exposure measurement at beginning of daughter's visit)

$t = 0$ and $T = 6$ hr implies Region III/True exposure = 1.03

$t = -10.5$ h and $T = 21$ hr implies Region III/True exposure = 1.045 (exposure measurement during midpoint of daughter's visit)

$t = 18$ h and $T = 6$ hr implies Region III/True exposure = 1.204

$t = 6$ h and $T = 18$ hr implies Region III/True exposure = 1.14

This leads to an overestimate for individual exposure segments of 3-20% assuming that measurements were always performed prior to the midpoint of the daughter's visit. The NRC staff could have included this correction, since measurement times were available and since estimates of daughter initiation and ending times of exposure were available. DRS believes the effect could be as large as 10% effect, an estimate which NRC staff could attempt to confirm by performing a more detailed reconstruction based upon availability of measurement times and estimates of the daughter's visiting hours. However, for general practice, such efforts are probably not warranted since the 10% improved achieved is small in relation to the total uncertainty of the reconstructed dose.

Daughter Tissue attenuation

Marcus et al. suggests that an attenuation correction (attenuation of I-131 gamma rays through 1 cm tissue) should have been applied. DRS believes that this correction is negligible or even > 1 , due to compensation of primary photon attenuation by backscatter from the daughter.

DRS estimated dose assuming Region III scenario

Based on this review, DRS estimates TEDE to be

$$\text{TEDE} = 15 \text{ Rem} \times 0.65 \times 0.90 = 8.8 \text{ Rem}$$

This estimate assumes the same distance-dwell time distribution as Region III

Reconciliation of SJH and Region III dose-reconstruction efforts

Based on review of material submitted by the Licensee, it is clear to DRS that the Licensee made significant efforts through retrospective interviews and records review to reconstruct the daughter dwell times and used of shielding. This reconstruction is both more detailed and closer in time to the incident than NRC's Region III effort. In addition, SJH continues to challenge NRC's calculations on technical grounds. DRS believes that NRC can be criticized for not making a more thoughtful and balanced effort to reconcile the two reconstruction scenarios.

Based on our admittedly relatively superficial view, DRS proposes the following alternative reconstruction scenario:

- During the period 7/2-7/4, we can assume the shields were in place and the daughter was standing behind them.
- Approximating I-131 by Ir-192, NCRP 49 indicates the transmission through 1" Pb shields to be about 0.02
- In a best case scenario, DRS assumes the daughter's body core was fully behind the shield
- In a worst-case scenario, DRS assumes that the daughter leaned over the shields with elbows, head and neck exposed to unshielded radiation field. DRS assumes a 50% occupancy ratio in this position, although no data are available to justify this or any other assumption.
- In both the worst and best case scenarios, DRS assumes that the daughter's minimum distance is limited by the shield, the distal surface of which can be no closer than 55 cm to the patient's center.
- The unshielded 55 cm exposure is given by MC to be about 41% of the 20 cm (beside measurement point) rate.

DRS notes that its postulated distance and dwell time scenarios are extremely conservative. Basically, the daughter was assumed to have positioned herself as close to the patient as geometrically possible and remained there 100% of the exposure time. On the other hand, neither Region III nor the Licensee are able to provide factual data justifying other scenarios. Region III inspectors believe that the daughter performed routine care duties, such as bathing the patient, and may have been even closer to the patient than the bedside measurement distance.

Best case = $0.9 \times (0.02 \times 0.41 \times (2.088 + 3.0 + 2.52)) + 0.65 \times (3.25 + 2.71 + 1.23) = 4.3 \text{ Rem}$

Worst case = $0.9 \times (0.51 \times 0.41 \times (2.088 + 3.0 + 2.52)) + 0.65 \times (3.25 + 2.71 + 1.23) = 5.6 \text{ Rem}$

Summary

- DRS believes that the 15 Rem estimate represents the most conservative estimate one could make that is not totally implausible. More sophisticated distance reconstruction techniques and common-sense evaluation of geometry (bed widths, etc) suggests that reducing this estimate by 40% is reasonable, assuming the Region's dose-time-distance scenario.
- DRS believes that the NRC should have considered the licensee's more detailed and contemporaneous dose reconstruction efforts. Where a dispute arises over dwell times, shield usage, etc. between NRC inspector reports and licensee interviews, both versions should be described in the inspection report and a range calculated based on bracketing scenarios. Of course, DRS assumes that both licensee and NRC inspectors are acting in good faith and that no one is intentionally trying to distort the truth.
- While details of space-time occupancy are very difficult to reconstruct retrospectively, both NRC inspectors and licensees are obligated to apply common sense in selecting distances, accounting for geometric constraints imposed by bed sizes and shield positions.

- In this particular case, DRS is comfortable citing a 4-9 Rem figure based on testimony from various parties. In routine cases where MC is not available, use of analytic line source or extended volume source formulas should be used since inverse square law will underestimate exposures near extended sources.
- In contrast to the Marcus-Siegel report, which challenges the Region III calculation mostly on methodological grounds, DRS finds that the greatest source of uncertainty is associated with assumed daughter dwell times and use of body shields. The assumed distance is also highly uncertain. However, neither Region III nor the licensee are able to provide factual data upon which an uncertainty analysis could be based.
- As suggested by the Marcus-Siegel paper, DRS used a computational approach (Monte Carlo simulation) to estimate a patient center-to-bedside detector distance. This reconstructed distance provides a rational basis for reducing NRC's dose estimate by 35%. However, DRS believes that inverse-square law, as proposed by Marcus and Siegel, applied to a single measurement is not appropriate in this case.
- The DRS reconstruction effort used Monte Carlo tools and more elaborate computational models than are normally applied in the field. These efforts were undertaken at the request of the Commission because this individual case has prompted a National debate. In routine cases, DRS believes that such efforts may not be warranted. It believes that effort should be directed more towards the "basics" of time, distance, and shielding utilization. The uncertainties associated with these assumptions overwhelm the issues of computational methodology.