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August 1, 2005

Ms. Amy M. Snyder, Senior Project Manager
Office of Nuclear Material Safety and Safeguards
Division of Waste Management and Environmental Protection
United States Nuclear Regulatory Commission
Washington, D.C. 20555-0001

RE: Docket No. 40-6563
TAC No. L51568
NRC License STB – 401

Dear Ms. Snyder:

As per my letter sent to you on July 14, 2005 attached are Mallinckrodt's responses relative to NRC's draft health physics and dose modeling comments on the Phase II Decommissioning Plan which were discussed at a meeting held on December 16, 2004.

Also, as previously stated in the above letter, Mallinckrodt plans to respond by September 1, 2005 to the Request for Additional Information found in Enclosure 2 of your letter to me dated June 29, 2005.

Very truly yours,

James K. Grant
Director, Environmental Remediation

CC: Pat Duft
Karen Burke
Henry Morton

Responses to NRC Request for Additional Information about Mallinckrodt's C-T Phase II Decommissioning Plan

RAI Group 1
August 1, 2005

Responses to NRC Inquiries About C-T Phase II Decommissioning Plan

INQUIRIES BY JAY THOMPSON

1. §9.5 Changes Licensee May Make without NRC Approval

   Change item j to:

   j. the Type I decision error (for Scenario A of NUREG-1505) or the Type II decision error (for Scenario B) will not be increased beyond 0.05;

   Add an item l:

   l: following failure of a final status survey, a survey unit will not be subdivided and reclassified without NRC approval.

   Add an item m:

   m: Scenario B of NUREG-1505 will not be used unless approved by the NRC.

   Response:

   1.1. Item j:

   CT 2 DP §14.4.3.4 "Selection of LBGR and Tolerable Decision Error," describes proposed conditions concerning decision error. It specifies they are based on consideration of the consequence of making an incorrect decision about whether a survey unit complies with radiological criteria for release. §14.4.3.4 also specifies that the target value of Type 1 (α) decision error, applicable to Scenario A hypothesis testing, will be 0.05. Selection of any greater value, not to exceed 0.15, will depend on consideration of these factors and documentation of the reasons in the survey report and will require NRC approval. This is not incompatible with the NRC recommendation to change §9.5, item j.

   NUREG-1757, 2, §A.7.2, recognizes that a value of $\alpha > 0.05$ may be considered when the relative shift, Δ/σ_s, is so small as to prescribe an unreasonably large number of samples. Our proposal to consider $\alpha \leq 0.15$ in studied circumstance is compatible with this §A.7.2.

   NUREG-1757, 2, §4.4 and NUREG-1727, §14.4, expect values for decision errors, α and β, with justification for α values > 0.05 applicable to Scenario A hypothesis testing. CT 2 DP, §14.4.3.4, provides justification specifying criteria to be considered if $\alpha > 0.05$ were to be considered and specifying that α not exceed 0.15 for Scenario A or separately for Scenario B. Nevertheless, CT Phase II DP §9.5 item j, §14.4.3.4, §14.4.3.5, and §14.4.3.8 are revised to conform to NRC staff interest that Comment items 1.j, 17, and 26 concern constraint on Type I decision error. CT Phase II DP §9.5 item j, §14.4.3.4, §14.4.3.5, and §14.4.3.8 are being revised to conform to NRC staff interest that Type I decision error (for Scenario A of NUREG-1505) or the Type II decision error (for Scenario B) will not be increased beyond 0.05 without concurrence by the NRC Project Manager. Timely concurrence within 4 business days may be sought in order to avoid delaying decommissioning activity.

1.2. Item l:

MARSSIM §8.5.3, p. 8-24, provides an example accepting subdivision of a Class 2 survey unit and reclassification of part of it to Class 1 in the event part fails. (Note that DP §9.5, item k, would require NRC approval for change to reduced classification, *e.g.*, from Class 1 to Class 2.)

In the event a minor part of a survey unit exceeds $DCGL_W$, MARSSIM §8.5.3, p. 8-24, provides an example accepting remediation the part of a Class 1 survey unit that exceeds $DCGL_W$, followed by remediation control survey, and demonstration of conformance without necessarily having to perform another final status survey in entirety.

1.3. Item m:

NUREG-1505 states,

> When the $DCGL_W$ is small compared to measurement or background variability, Scenario B should be chosen. This is because contamination below the $DCGL_W$ will be difficult to measure. Requiring additional remediation when it is not necessary, may essentially require remediation of background. This is an impossible task. Releasing a survey unit that has residual radioactivity within the range of background variations is a less severe consequence in this case. It is fairly straightforward to specify what is meant for a survey unit to meet the release criterion, but a survey unit may be distinguishable from background either because it is uniformly contaminated or because it contains spotty areas of residual radioactivity. For this reason, the data analysis for Scenario B involves two statistical tests performed in tandem.[1]

Coal cinder fill comprising soil in Plant 5 contains variable concentration of uranium series and thorium series radionuclides, the same as residual uranium series and thorium series in soil from licensed operations. As noted in NUREG-1505, the Scenario B hypothesis may be appropriate. Mallinckrodt is concerned about the prospect of a long time for NRC approval in the event Scenario B is preferable; otherwise, removal of large amount of soil practically indistinguishable from background in the cinder fill might be the consequence.

DP 14.4.3.3 and §14.4.3.8 propose that if a non-parametric statistical test is failed, Mallinckrodt may reverse the tested hypothesis and apply an alternate, appropriate statistical test, *e.g.*, from Scenario A to Scenario B.[2] Nevertheless, NRC staff expects the licensee to seek approval to apply Scenario B before using it. CT 2 DP, §9.5, item m will be revised to specify that Mallinckrodt may use the Scenario B hypothesis (ref. NUREG-1505 §2.3.1 and MARSSIM §2.6.2) without filing an application for an amendment to the license to change the decommissioning plan provided the NRC Project Manager concurs that the Scenario B hypothesis may be used to test a final status survey in lieu of the Scenario A hypothesis. CT Phase II DP §9.5, §14.4.3.3,

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1 Gogolak, C.V., *et.al.*, NRC:NRR. *A Nonparametric Statistical Methodology for the Design and Analysis of Final status Decommissioning Surveys*. NUREG-1505, rev 1. §2.3.1, p. 2-10. June 1998.

2 NUREG-1505, §2.5.

§14.4.3.4, and §14.4.3.8 are being revised to be consistent with respect to prospective use of the Scenario B hypothesis.

2. Table 4-7 contains the radiological results (designated BH-001 through BH-056) from subsurface sampling conducted per the C-T Characterization Plan. Many of the boreholes (BH-009 to BH-056) have samples with the top sample depth listed as 0 feet. However, the sample results appear to be at incremental depths and not averages over the whole column. For example, BH-030 has U-238 samples results of 14.6 pCi/g for 0-12.5 ft and 6.3 pCi/g for 0-14.5 ft. This is inconsistent since it would take another 12.5 feet at zero concentration to reduce the concentration to 7.3 pCi/g if the average concentration is 14.6 pCi/g for 0-12.5 ft. However, the concentration in the table for 0-14.5 ft is less than this with the addition of only two feet. Please review the table and revise the upper limits.

   Response:

   Table 4-7 is being revised to include both a top and bottom sample depth for samples from soil core locations 009 through 056. The revised sample depths were determined by comparison of sample log book entries to the hand auger or split spoon depth range described on the respective boring log. A sample increment of one foot was estimated for most cases. The sample log book entry was assumed to coincide with the middle of a respective one-foot sample interval. These estimates are internally consistent with respect to other boreholes within the subjected sampling event. Exceptions to the one-foot sample increments were those cases where top of sample was defined by the bottom of the overlying pavement, or the bottom of the sample was defined by the end of the borehole.

3. Please review the data for BH-065 and BH-066 in Table 4-8 for appropriate top sample depths.

   Response:

   Review of chain-of-custody and sample logbook entries provide information for the following conclusion about top of sample depths.

   - BH-065
     - The first sample had its top depth = 0.0 and bottom depth = 1.0 foot
     - The second sample had its top depth = 3.0 feet and bottom depth = 4.0 feet.
   - BH-066
     - The first sample had its top depth = 1.0 foot and bottom depth = 4.0 feet.
     - The second sample had its top depth = 3.0 feet and bottom depth = 4.0 feet.

   CT 2 DP Table 4-8 is being revised to state these sample depths.

4. Chapter 5: Please clarify if the soil and pavement scenarios are independent, i.e., if exposures to pavement/slabs and soil are mutually exclusive.

   Response:

   The scenario of exposure to bare soil, on which DCGL for soil were derived, and the scenario of exposure to pavement, on which DCGL for pavement were derived, cannot occur simultaneously.

Exposure to bare soil and to pavement cannot occur simultaneously. The scenario assuming bare soil necessarily excludes pavement and any exposure to it. Without pavement, exposure pathways to pavement are absent. Thus, DCGL derived for soil are independent of presence of or contribution from pavement.

On the other hand, pavement and its crushed stone base would exist atop soil. When so, it would be a complete barrier against airborne and ingestion pathways of exposure to conceivable residue in the soil and an incomplete shield against gamma radiation penetrating from conceivable residue in the soil. With the aid of dose modeling of outdoor exposure to gamma radiation penetrating nominal 4-inch-thick pavement by RESRAD, one finds that 2 meters of soil containing $DCGL_W$ concentration of 3 U-to-1 Th series source would be estimated to contribute 3.8 mrem/yr through the pavement. Subtracting that from 25 mrem/yr allotted to DCGL would imply reduction of conceivable contribution from residue on pavement itself to 0.85 of the $DCGL_W$ derived for pavement and would eliminate question of allocation of maximum acceptable total dose.

Although it is unlikely that both soil and pavement would be contaminated to more than 0.85 of either $DCGL_W$, and thus are practically independent, $DCGL_W$ on pavement in CT 2 DP §5, Table 5-3, is being reduced by 0.15.[3] Together with revisions in response to item 48, values in Table 48-2 herein become the revised $DCGL_W$ to be applied. As a consequence $DCGL_{EMC}$ will also be reduced to nominally 0.85 of currently proposed values in Figure 5-2 (now identified as Table 5-4).

5. The cost estimate in the first paragraph of section 7.4.2 is $347,000 while the calculation below it totals to $367,400.

   <u>Response:</u>

   In §7.4.2 ¶1, the value, $347000, is to be revised to $367400.

   In §7.5.1, ¶3, $Cost_T$ equation is to be revised to state $367400 instead of $347100. The total $Cost_T$ will be revised from $756198 to $776498.

   In §7.5.1, ¶4, the value, $756000, will be revised to rounded $776000.

   In §7.5.2, ¶2, the value of Conc ÷ $DCGL_W$ = 33 will be revised to = 34 in all occurrences.

6. The cost estimate in the first paragraph of section 7.4.3 is $397,000 while the calculation below it totals to $395,500.

   <u>Response:</u>

   In §7.4.3, ¶1, the value, $397000 is to be revised to $395500.

7. Section 8.4.3 states "Downstream sewerage will reasonably be assumed to be uncontaminated if surveys of drains and other at-grade locations do not identify the presence of radioactivity above criteria." However, if at-grade locations have been decontaminated,

[3] Existing Table 5-3, concerning $DCGL_W$ in soil of a construction scenario, is being omitted. Existing Table 5-3, concerning $DCGL_W$ on pavement, will be renumbered to become Table 5-2.

contaminated sediment may still be present. Provide the technical and/or historical basis for the proposed survey/sampling or modify the plan.

Response:

The item of interest relates to drains and sewerage that served C-T support buildings. They would have posed low potential for contaminating sewerage. After cessation of C-T operation, at-grade and below-grade drains or sewerage from the support buildings have not been decontaminated purposefully; although years of use and or nearby facility discharge may have flushed the sewerage practically clean of historical content.

C-T support buildings and downstream access to their sewerage for sediment sampling are identified in Table 7. This access for characterization sampling and for final status survey sampling should be adequate to determine the residual source material status in the sewerage.

Table 7. Sewerage Downstream of C-T Support Buildings

Building	Function	Downstream Sewerage Access
213	Change & break rooms	Via manhole & surface drains [ref. CT 2 DP Fig. 4-1]
214	Transformer & switchgear room	Via manhole & surface drain [ref. Fig. 4-1]
235	Feed material & URO storage	Via 3 to 5 manholes [ref. Fig. 4-1]
236	Maintenance area & product drying	Via 4 to 6 manholes [ref. Fig. 4-1]
246A	Offices	Via manholes [ref. Fig. 4-1] The nearest downstream manhole sample > $DCGL_W$ (surface). That sewerage section is to be removed.
250 labs	Offices & quality control labs	Sewer downstream of Building 250 labs enters sewerage that served C-T process buildings 238, 247B, & 248. DP §8.4.2 describes how the downstream sewerage contaminated by C-T processing will be surveyed and or plugged or removed.

8. Sections 8.5.1 and 8.7: the NRC should be notified prior to backfilling an excavation as specified in Section 8.7. However, "timely NRC response" prior to backfilling is too ambiguous. Please include an allowance for a 14 calendar day notification.

Response:

In §8.7, the sentence, "If timely NRC response is not received, excavations may be surveyed or otherwise delineated (e.g., with a marker layer) and backfilled." will be revised. The revised sentence will state, "If timely response from the NRC Project Manager is not received within two business days after notification, excavations may be surveyed (*e.g.*, geographically) or otherwise delineated (*e.g.*, with a marker layer) and backfilled."

9. Section 8.5.1: Please clarify if a survey will be performed after backfilling an excavation, in addition to the one of the excavation prior to backfill.

   Response:

   No additional survey of the excavated and backfilled area is planned. Assuming the bottom of the excavation cavity is accessible for final status survey and backfill is either clean soil or has been characterized by MARSSIM-like survey quality, these data should be sufficient to demonstrate a backfilled excavation area to comply with radiological criteria for release. In the event groundwater were to prevent direct access to survey the bottom of an excavation cavity, an alternative would be to backfill as much as one meter and do final status core sampling through the backfill into the unexcavated bottom. Adjacent land not requiring excavation in the same survey unit will be subject to soil core sampling and analysis to complement the final status survey. DP §8.5.1 is being revised to incorporate this response.

   Separately, Mallinckrodt is obligated to comply with characterization for chemicals and metals as required by the RCRA and as may be required to characterization waste for disposal.

10. Footnote 2 on page 14-1 states: "A subsurface building foundation within a soil survey unit that passes a FSS will also be assumed to pass FSS and will not be sampled." Please explain why this is adequate or provide more information concerning construction, given that radioactive material may have been present along seams at slab-foundation joints.

    Response:

    Merit of this assumption rests on expectations that exposure potential is low because:

    - if source material migrated via a joint adjacent a foundation, it would not migrate into nor concentrate in a solid concrete foundation to substantially greater concentration than in adjacent soil;
    - the portion of a foundation that is below grade is ordinarily buried in soil;
    - foundation exposed by excavation would not remain exposed any longer than the adjacent excavation cavity remains;
    - consideration of relation of surficial, or areal, $DCGL_W$ and soil mass $DCGL_W$ discussed in response to item 48 (ref. response to item *h* in EPAD staff comments); and
    - if foundation were removed, it would be broken into rubble containing no more residual concentration than adjacent soil.

    Above-grade, exposed portions of a foundation are subject to the DCGL that is applicable to pavement and will be subject to final status survey. In the event the exposed portion of a foundation or adjacent portion of a slab in contact with it were contaminated above DCGL applicable to pavement, Mallinckrodt would investigate the possibly affected part of the foundation below grade. A foundation may be surveyed either by direct measurement or by collecting sample(s) of concrete from the foundation surface, *e.g.*, by scabbling, scraping, or chipping. Residual source in that kind of sample would be measured, interpreted as areal contamination, and compared with the areal DCGL applicable to pavement.

DP §14.4.3.7, "Surveys," is being revised to describe this particular final status survey process.

11. Footnote 3 page 14-2: page 18 of DG-4006 is referenced. The citation is on page 15 of my copy of DG-4006. Please verify the page number or cite "Section 2.9" of DG-4006.

    Response:

    CT Phase II DP,page14-2, footnote 3 is being revised from reference to DG-4006, p. 18 to DG-4006, §2.9.

12. On page 14-3, last paragraph of Section 14.2, it is stated that: "Where Characterization Survey data are insufficient in number to serve as the entire data set for a particular survey unit, those data may be supplemented, where appropriate, by additional FSS measurements using a statistically based sampling design, such as a two-stage sampling plan." Please add that any such plan will be reviewed to ensure it meets DQOs such as the allowable Type I and II errors.

    Response:

    DP §14.2 will be revised to specify that such plan will be reviewed to ensure that it meets DQO.

13. On page 14-3, third paragraph of Section 14.3, it is stated that: "Where remedial action survey data are insufficient in number to serve as the entire data set for a particular survey unit, those data may be supplemented, where appropriate, by additional FSS measurements using a statistically based sampling design, such as a two-stage sampling plan." Please add that any such plan will be reviewed to ensure it meets DQOs such as the allowable Type I and II errors.

    Response:

    DP §14.3 will be revised to specify that such plan will be reviewed to ensure that it meets DQO. [ref. NUREG-1757, 2, apx C]

14. In section 14.4.1, it is stated that: "Typical instrumentation is listed in Tables 14-1 (field methods) and 14-2 (laboratory methods). Other instrumentation meeting requisite detection capabilities may be used provided it meets quality objectives for calibration, operability, and detection capability." The licensee should commit to providing a technical basis document to the NRC prior to use that demonstrates the new instrumentation meets quality objectives.

    Response:

    Mallinckrodt is agreeable to developing a technical basis document demonstrating that any instrument type used in lieu of those named does meet quality objectives. Each such document will be developed before the instrumentation is used and will be available on-site for NRC inspection.

15. In the last paragraph of Section 14.4.3.2, page 14-11, the classification of temporary paving is discussed. It is stated that "All of this material in Class 1 areas and some of this material in Class 2 areas will be removed to allow FSS surface contamination measurements as part of the Phase II Plan. The material removed has very low potential for contamination, and will be considered non-impacted subject to confirmatory survey to determine that average radionuclide concentration does not depart significantly from background." However, this paving is in close proximity to or in contact with radioactive material in Class 1 and 2 areas. Please provide further justification as to why this material should be considered non-impacted or Class 3.

Response:

Temporary pavement has low potential for contamination and when removed, is not expected to contain residual source contamination that is distinguishable from natural background nor exceed a small fraction of $DCGL_W$. Reasons why are:

- Plant 5 street surface characterization survey results are that only 3 of 1670 measurements exceeded the $DCGL_W$ proposed in Table 5-3 for pavement surface, thereby providing confidence that street surfaces beneath the temporary pavement are not contaminated significantly.
- Plant 5 streets continued to be subject to rain after the characterization survey.
- Loose, imported gravel was spread on pavement and slabs before applying temporary pavement. It will facilitate removal of the temporary pavement and as a buffer between original and temporary pavement will mitigate transfer of contamination to temporary pavement.
- The temporary pavement was imported and thereby was without residual source contamination when installed.

For these reasons, temporary pavement cap is not expected to be contaminated.

Even so, confirmatory measurements looking for residual source material would be performed before releasing the temporary pavement rubble from the site. Such confirmatory survey will be performed as specified in written procedure.

16. In Section 14.4.3.3, it is stated that "Alternatively, the tested hypothesis may be that measurements in a survey unit do not exceed background + $DCGL_w$, i.e., Scenario B, and apply alternate, appropriate statistical test(s)." Please add a note that if Scenario B is used, NRC approval is required.

Response:

CT 2 DP §14.4.3.3 will be revised to add text, "In the event Mallinckrodt intends to test compliance using Scenario B, it would notify the NRC Project Manager and would expect response within 4 business days before implementation.

17. In Section 14.4.3.5, page 14-14, it is stated that "The required number of measurements determined in the first iteration may exceed reasonable bounds. The process can be repeated using more suitable values of Δ, α, and β as appropriate." Please add a note that NRC

approval is required for using α or β values greater than 0.05, per Section 14.4.3.4, page 14-12.

Response:

We proposed β value be constrained to the same as α value, partly in compensation for acceptance of $\alpha = \beta \leq 0.15$ after DQO review. Item 1 proposes only that Type I decision error (α) be constrained to ≤ 0.05. CT Phase II DP §9.5 item j, §14.4.3.4, §14.4.3.5, and §14.4.3.8 are revised to conform to NRC staff interest that Type I decision error (for Scenario A of NUREG-1505) or the Type II decision error (for Scenario B) will not be increased beyond 0.05 without concurrence by the NRC Project Manager. Timely concurrence within 4 business days may be sought in order to avoid delaying decommissioning activity.

18. In Section 14.4.3.5, page 14-16, it is stated that "Scanning is unnecessary for Class 3 building slab and pavement survey units." Please change to indicate that judgmental scanning is performed for Class 3 areas. Note that the last paragraph of Section 14.4.3.7 does recognize that scans of Class 3 areas will be performed.

Response:

The topic addressed in §14.4.3.5, p. 14-16, is related to survey design, especially concerning number of unbiased samples required and their spacing. Since survey design in a Class 3 survey unit is not driven by the elevated measurements criterion, scanning is not required for that determination. That is the point of the statement of concern on page 14-16. §14.4.3.5 will be revised to clarify this.

Whereas, DP §14.4.3.7, p. 14-19 acknowledges scanning is intended in Class 3 units. As noted by the comment and by the MARSSIM, scanning in a Class 3 unit is intended to search in locations judged to have the most potential for elevated contamination. §14.4.3.5 and §14.4.3.7 will be revised to clarify these separate purposes.

19. Footnote 19 on page 14-16 states "$n_{wilcoxon}$ = number of measurements needed to provide desired confidence in a Wilcoxon Rank Sum test, as calculated from either Equation 14-1 or 14-2". However, These equations give an N equal to the total number of measurements (survey area and background). Please clarify that $n_{wilcoxon}$ is N/2, not N, for comparison to n_{EA} in the last paragraph of Section 14.4.3.5.

Response:

Text on DP page 14-14, between equations 1 and 2 state the application of "N" clearly. Clarification of correct definition of $n_{wilcoxon}$ will be made in footnote 19 in §14.4.3.5.

20. In Section 14.4.3.8, page 14-20, under the paragraph Evaluation of Measurements Individually, it is stated that "...An investigation level depends on survey unit classification. A scan result which exceeds the corresponding investigation threshold listed in Table 14-5 shall be confirmed by stationary location measurement. Scan measurement results will remain as paper records. The direct measurement data only will be recorded and used for further analysis and classification." In the next paragraph, it is noted that "Scan results for

those units subject to scanning will also be compared to investigation levels." Scan results may also be used to define the extent of elevated areas of contamination. Please clarify the use of scan data. It seems like scan results are used for further analysis and classification.

Response:

The effect of scanning sensitivity on the number of systematic measurements is described in relevant §14.4.3.5 and notably on pages 14-15 and 14-16.

The purpose of scanning is to search for elevated radioactivity as described in §14.4.3.7. If elevated radioactivity is found, it is compared to an investigation level. Investigation levels for scanning are described in §14.4.3.8 on pages 14-20 and 14-22, including Table 14-5. If investigation confirms the scanning observation, additional scanning, stationary measurements, and or sampling would be done to delineate and assess the area of elevated radioactivity. Once an elevated radioactivity area is delineated, need for reclassification or compliance with release criteria, i.e., $DCGL_{EMC}$, would be evaluated by stationary measurements or sampling. Scanning results would not be entered into that database.

21. In Section 14.4.3.8, page 14-21, it is stated that "Depending on the outcome of the elevated measurement test and other tests, resurvey, reclassification, partial or complete remediation, or some combination of these measures may be required. (If only partial remediation is required, resurvey of some portion of the unit after supplementary remediation will also be required. To the extent practical and appropriate, original survey data from portions of the unit outside the supplementary remediation area will be used in conjunction with new survey data from the supplementary remediation area in new tests to determine whether the unit meets release criteria.)." Please note that NRC concurrence is required for subdividing and partial reclassification of a survey area. Also, a partial remediation (e.g., cleanup of a small area exceeding the $DCGL_{EMC}$) without an entire resurvey of the whole survey area may be performed if the survey area as a whole passed originally.

Response:

The MARSSIM provides an example of reclassification of part of a survey unit to higher classification, *e.g.,* from Class 2 to Class 1, to provide for increased sampling density in a portion without reclassifying the entire survey unit.[4] It also describes remediation and another final survey if average concentration in the survey unit exceeds $DCGL_W$ over a majority of its area.[5] These seem to represent the MARSSIM and the NRC staff comment. If subdividing a survey unit and reclassifying part of it is the logical remedy, it will be done in accordance with provisions in §14.4.3.9 *Contingencies.*[6] NRC concurrence of proposed subdivision and reclassification would be sought as noted in revised DP §14.4.3.8 "Investigation Levels," and §14.4.3.9 *Contingencies.* See also response 1.2 to item 1, sub-item L herein.

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[4] MARSSIM. NUREG-1575, §8.5.3, p. 8-24.

[5] MARSSIM. NUREG-1575, §8.5.3, p. 8-25.

[6] DP Section 14.4.3.9 *Contingencies* was subdivided from DP §14.4.3.8.

22. For the scanning investigation level for Class 1 slab and pavement in Table 14-5, p. 14-22, the alternate limit of MDA is redundant since the $DCGL_{EMC}$ may be a function of the MDA. Recommend deleting "or MDA".

    Response:

    "or MDA" is being deleted from Table 14-5, Class 1 slab and pavement row.

23. Please clarify in Table 14-5 that the Class 1 slab and pavement investigation levels also apply to surface soils.

    Response:

    DP §14.4.3.8 subsection "Investigation Levels" is being revised to apply investigation levels proposed for slab and pavement also to topsoil interval wherever topsoil is exposed. Note that practically all land area is covered by buildings or pavement.

24. On page 14-23, in the paragraph on Low Level Screening, it is stated that "If the class 3 survey unit contains no flagged measurements, the unit will be rated acceptable, and no further evaluation will be needed." An implicit assumption is that the MDA is less than the $DCGL_W$. This is covered in the next paragraph on page 14-23. Please add that it is necessary to demonstrate that the average concentration is less than the $DCGL_W$, and delete the "no further evaluation" comment.

    Response:

    §14.4.3.8, subsections "Low Level Screening" and "$DCGL_W$ Limit Screening" are being revised to implement this suggestion. Individual measurements are screened in subsections "Min/Max Screening" and "Low Level Screening." Testing of average concentration in a survey unit is specified in the subsection "$DCGL_W$ Screening."

25. In Table 14-6, the second survey result is "Difference between any survey unit measurement and any reference area measurement greater than $DCGL_W$ (not to be used for survey units with less than 5 measurements)". Please add a condition to the first survey result (all survey measurements less than the $DCGL_W$) to indicate that the minimum number of measurements should also apply to the first survey result.

    Response:

    $N_{wilcoxon}$ measurements might be unreasonable in a survey unit that is small in area. In such a small survey unit containing 5 or fewer measurements, the criterion, specified in §14.4.3.8, page 14-26, is that every one of those measurements shall not exceed $DCGL_W$ (net of background).

    Because 5 or fewer measurements would be an unreasonably small population for a WRS test, and because a WRS test is a consequence of the second provision, the exclusion for 5 or fewer measurements is in the second provision.

    However, a premise of compliance is that if every measurement complies with the $DCGL_W$ criterion, then the entire survey unit complies. For that reason, a qualification on number of measurements is not needed for the first provision in Table 14-6.

26. In Section 14.4.3.8, page 14-26, possible actions are listed if DQO are inappropriate or if a survey unit is misclassified. The first bullet states Mallinckrodt may "Review the DQO. If warranted, adjust values of parameters such as Type I and Type 2 error criteria or the lower bound of the gray region (LBGR)." Changing Type 1 or Type 2 error criteria may require NRC concurrence. Please add a note that these actions listed may require NRC concurrence.

    Response:

    Comment items 1.j, 17, and 26 concern constraint on Type I decision error. CT Phase II DP §9.5 item j, §14.4.3.4, §14.4.3.5, and §14.4.3.8 are being revised to conform to NRC staff interest that Type I decision error (for Scenario A of NUREG-1505) or the Type II decision error (for Scenario B) will not be increased beyond 0.05 without concurrence by the NRC Project Manager. Timely concurrence within 4 business days may be sought in order to avoid delaying decommissioning activity.

27. In Section 14.4.3.8, page 14-26, possible actions are listed if DQO are inappropriate or if a survey unit is misclassified. The second major bullet deals with reclassification of a part of the survey unit. While this may be acceptable in some cases, approval depends on the specific circumstances. Add a condition that NRC approval is required.

    Response:

    If subdividing a survey unit and reclassifying part of it is the logical remedy, it will be done in accordance with provisions in §14.4.3.9 *Contingencies*.[7] NRC concurrence of proposed subdivision and reclassification would be sought as noted in revised DP §14.4.3.8 "Investigation Levels," and §14.4.3.9 *Contingencies.*

    See also response to item 1, sub-item 1.2 L and in item 21 herein. Resolution will be the same as mentioned for item 21. Section 14.4.3.9, (previously in §14.4.3.8, page 14-26) would be revised appropriately to implement the resolution.

28. In Section 14.4.3.8, page 14-26, possible actions are listed if DQO are inappropriate or if a survey unit is misclassified. The second major bullet states "If the reclassified part were Class 1, the measurement density appropriate for Class 1, and the number of measurements in it were fewer than would be estimated for an entire Class I survey unit, compliance would be accepted if every measurement in the reclassified part were less than the $DCGL_W$." Surveys must consist of enough samples to be statistically significant. Acceptance of a unit with the number of samples "fewer than would be estimated for an entire Class I survey unit" is too case-specific to grant on a general basis. However, in certain circumstances, fewer samples may be acceptable. Please add a condition that NRC approval is necessary to use alternate criteria. Also, please add a note that the reclassified area, now Class 1, would need a 100% scan.

    Response:

    MARSSIM guidance on this item is:[8]

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[7] DP Section 14.4.3.9 *Contingencies* was subdivided from DP §14.4.3.8.

[8] MARSSIM. NUREG-1575, §4.6, p. 4-15.

Special considerations may be necessary for survey units with structure surface areas less than 10 m^2 or land areas less than 100 m^2. In this case, the number of data points obtained from the statistical tests is unnecessarily large and not appropriate for smaller survey unit areas. Instead, some specified level of survey effort should be determined based on the DQO process and with the concurrence of the responsible regulatory agency. The data generated from these smaller survey units should be obtained based on judgment, rather than on systematic or random design, and compared individually to the DCGLs.

The content of interest on DP page 14-26 is intended to provide a framework to implement the MARSSIM guidance with sufficient written specificity to gain NRC concurrence for application in accordance with these specifications in lieu of case-by-case concurrence. The specifications proposed include a survey measurement or sampling density no less than derived by a survey design for the survey unit classification.

Especially because the number of measurements needed for WRS or other population statistical testing may be unnecessarily large in a small survey unit, we specified that compliance require that each measurement be < $DCGL_W$. For if every measurement is < $DCGL_W$, the population mean (or median in the WRS test) will also be < $DCGL_W$.

A specification will be added to state that a Class I area, including area reclassified to Class I, would be subject to scanning in accordance with specification in §14.4.3.7, page 14-18. Further, before this alternative is implemented, Mallinckrodt would notify the NRC of intent to employ it.

29. In Section 14.4.3.8, page 14-26, it is stated "In the event a Class I survey unit area is less than 500 m^2 and the number of measurements are specified and tested statistically for compliance with $DCGL_W$, the area factor shall not exceed that specified in Section 5 for the elevated measurement test." It is not clear how the area factor is capped since equations with no maximum values are presented in Section 5. Please clarify how the area factor is limited.

    Response:

    Area factors for elevated measurements criterion in top soil and for pavement or slab are presented in Figures 5-1 and 5-2 respectively. The minimum area in each figure is 10 m^2. Ten square meters is the minimum area for which an area factor is provided; the corresponding area factor is the maximum acceptable value of area factor. §5.8.1.2 and §5.8.3.2 are being revised to clarify this boundary condition.

30. In Section 14.4.3.8, page 14-26, it is stated "Alternatively, in the event a Class 1 survey unit area is less than about 500 m^2, the number [of] measurements estimated to satisfy a WRS, Quantile, or Sign test might be unreasonably large in that survey unit. When both conditions exist, measurement density will be at least one measurement per 100 square meters at locations based on judgment. In that circumstance, the criterion for release shall be that every measurement in the survey unit does not exceed the $DCGL_W$." The thresholds for special consideration of small survey areas listed in the MARSSIM reference (page 4-15) are 10 m^2 for buildings and 100 m^2 for land areas. These are significantly smaller than the

500 m^2 proposed by the DP. Please justify the 500 m^2 area or change the text. Also add that NRC concurrence for the reduced coverage is necessary.

Response:

By the MARSSIM method, measurement density increases as survey unit area diminishes. In view of the economic cost of soil core sampling and analysis, consideration should be given to acceptance of relief from sampling density when it exceeds more than some multiple of the areal density designed to satisfy population statistics alone.

In a small-area survey unit, the number of measurements needed for population statistical tests may be unnecessarily large. In such small area, the level of survey effort should be decided by the DQO process, with survey locations based on judgment, and each measurement compared to the DCGLs.[9, 10] Presence of multiple principal radionuclides in the uranium series, actinium series, and thorium series, in the presence of natural background in cinder fill, and relatively low $DCGL_W$ imply about 20 to 40 measurement locations are a likely range to satisfy population statistics in Plant 5. In a Class I survey unit 2000 m^2 in area, the corresponding measurement location density would be 100 m^2 to 50 m^2. Earlier guidance, not based on population statistics, recommended 25 m^2 per measurement location as sufficiently dense. If so, a threshold area, 500 m^2 smaller than which more than one measurement per 25 m^2 would apply, would be

$$\text{area} = 500\ m^2 \div 20\ \text{meas} = 25\ m^2/\ \text{meas}$$

It would be rational, then, to recognize a threshold area about 500 m^2, below which the required measurement density would be no greater than 25 m^2/ measurement location. Above that, specification of measurement density for population statistics would tolerate a survey density as much as 4 times higher than is otherwise acceptable under MARSSIM guidance in a 2000 m^2 survey unit.

Mallinckrodt would be willing to adopt a threshold area = 500 m^2, below which would define a small-area, Class 1 survey unit; to specify a number of measurements equivalent to no larger than 25 m^2/ measurement location therein, located by judgment; to require each measurement to be $\leq DCGL_W$; and to seek NRC concurrence for each such small area, Class 1 survey unit. This represents a reasoned judgment in view of survey density and of the economic cost of soil core sampling and analysis. Furthermore, as explained in response to item 28, the content of interest on DP page 14-26 is intended to implement the MARSSIM guidance with sufficient written specificity to gain NRC concurrence for application in accordance with these specifications in lieu of case-by-case license amendment.

Specific Areas. Two small areas whose radioactive contamination causes their classification to differ from the larger areas surrounding them are identified in CT 2 DP, §14, Figure 14-2. One is southeast of Building 245; the other is east of Building 240. Since these are known small areas subject to alternate treatment in accordance with revised CT 2 DP, §14.4.3.9, and since the NRC staff asks notification and approval of such, John Buckley recommended that these two small areas be identified and justified in response to this NRC query item 30. These two small areas, related characterization survey data, and proposed final status survey treatment of each small area are described in Appendix 30 herewith.

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9 *op.cit.*

10 ref. response to item 28.

31. In Section 14.4.3.8, page 14-26, it is stated "In the event a Class 2 survey unit area is less than 2500 m^2, the number measurements estimated to satisfy a WRS test might be unreasonably large in that survey unit. When so, measurement density will be at least one measurement per 500 m^2 at locations based on judgment. The criterion for release in that circumstance, shall be that every measurement in the survey unit does not exceed the $DCGL_W$." MARSSIM does not propose a threshold for reduced coverage of a Class 2 area. Please justify the threshold of 2500 m^2, and add a statement that NRC concurrence is needed.

Response:

MARSSIM guidance quoted in response to item 28 is not specific to survey area classification. Conceptually, the same rationale should apply without regard to classification for accepting an area threshold below which enough measurements for population statistics are not required.

A revised proposed small-area, Class 2 survey unit area ≤ 2000 m^2 would be 0.2 of the maximum land area for a Class 2 survey unit suggested by the MARSSIM. Above this small area threshold of 2000 m^2, the areal density of measurement locations might be increased by as much as a factor of 5 over what might be allowed by the MARSSIM. In a small-area, Class 2 survey unit, consideration should be given to acceptance of relief from sampling density when it exceeds more than 5 times the areal density designed to satisfy population statistics alone. At the proposed threshold area, 2000 m^2, at least one measurement per 100 m^2 would be specified, which could require as many as 20 measurements.

$$\text{area} = 2000\ m^2 \div 20\ \text{meas} = 100\ m^2/\ \text{meas}$$

Mallinckrodt would be willing to adopt a threshold area = 2000 m^2, below which would define a small-area, Class 2 survey unit; to specify a number of measurements equivalent to no larger than 100 m^2/ measurement location therein, located by judgment; to require each measurement to be ≤ $DCGL_W$; and to seek NRC concurrence for each such small area, Class 2 survey unit. This represents a reasoned judgment in view of survey density and of the economic cost of soil core sampling and analysis.

Before this alternative is implemented, Mallinckrodt will notify the NRC of intent to employ it Furthermore, as explained in response to items 28 and 30, the content of interest on DP page 14-26 is intended to implement the MARSSIM guidance with sufficient written specificity to gain NRC concurrence for application in accordance with these specifications in lieu of case-by-case license amendment.

32. In Section 14.4.3.8, last bullet on page 14-26, it is stated "If the scanning method was not sensitive enough in a Class 2 unit, a portion containing measurements greater than $DCGL_W$ may be reclassified as Class 1, measured at the measurement density required for a Class 1 area, with the rest of the survey unit remaining Class 2." Please add that NRC concurrence is necessary.

    Response:

    Mallinckrodt is concerned about potential delay that might result while waiting for NRC concurrence. Before this alternative is implemented, Mallinckrodt will notify the NRC of intent to employ it and would expect NRC response within 4 working days. Newly numbered §14.4.3.9 (previously §14.4.3.8) is being revised to commit to notifying the NRC of this intent.

33. In Section 14.4.3.8, second bullet on page 14-27, it is stated "If a survey unit passes. Compute the radiological dose associated with each measurement as if it represented the entire survey unit and calculate the arithmetic mean dose represented by all the measurements in the area of elevated radioactivity. If the mean dose does not exceed the product, area factor x radiological dose criterion, *i.e.*, AF x $DCGL_W$, compliance would be demonstrated for the elevated measurements criterion for that local area." Note that "area factor x radiological dose criterion" and "AF x $DCGL_W$" do not have equivalent units. Please clarify which expression is correct.

    Response:

    The text of the second bullet has been deleted. Instead, revisions have been made to DP §14.4.3.7, §14.4.3.8, and newly numbered §14.4.3.9 to address elevated measurements more compatibly with the MARSSIM and eliminate the question concerning units of AF x $DCGL_W$.

    Scanning is used to identify locations within a survey unit that exceed the investigation level.[11] An investigation level is a radionuclide-specific level of radioactivity used to indicate when additional investigation may be necessary.[12] Scanning, investigation, and action prompted by investigation are described in §14.4.3.7 and in §14.4.3.8. Testing final status survey data of record, including elevated measurements, is described in DP §14.4.3.8. If final status survey data do not satisfy a screening test for $DCGL_W$ or $DCGL_{EMC}$, the MARSSIM provides for alternate testing, some of which are provided in revised §14.4.3.9.

    Revisions concerning investigation have been made to §14.4.3.7 ¶"Class 3 Areas," and in §14.4.3.8 ¶"Investigation Levels."

    Revisions concerning screening of elevated measurements have been made in §14.4.3.8 ¶"Elevated Measurement Comparison (EMC) Screening."

    In the event alternate testing of a survey unit may be appropriate, DP §14.4.3.9 "Contingencies" (separated from previous §14.4.3.8) provides for alternate means of assessing compliance with release criteria.

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[11] MARSSIM. NUREG-1575, §5.5.3, p. 5-46.

[12] MARSSIM. NUREG-1575, §5.5.2.6, p. 5-44.

34. In Section 14.4.3.8, second bullet on page 14-27, it is stated "If a survey unit passes. Compute the radiological dose associated with each measurement as if it represented the entire survey unit and calculate the arithmetic mean dose represented by all the measurements in the area of elevated radioactivity. If the mean dose does not exceed the product, area factor x radiological dose criterion, *i.e.,* AF x $DCGL_W$, compliance would be demonstrated for the elevated measurements criterion for that local area." This is different than Equation 8-2 on p. 8-23 of the MARSSIM. Please add a condition to comply with Equation 8-2.

Response:

§14.4.3.8 "Data Analysis," ¶ "Elevated Measurement Comparison (EMC) Screening" provides:

> In the event that an area of elevated radioactivity is identified above $DCGL_W$, an additional test is performed to ascertain whether the overall radioactivity concentration in the survey unit is greater than the release limit.[27] Following determination of the size of the elevated area and radioactivity concentration therein, a sum-of-fractions rule[28] should be used to ascertain whether the radioactivity concentration over all of the survey unit is less than the $DCGL_W$. To pass the test, the combined contribution from the elevated area and the remainder of the survey unit must conservatively be less than 0.95 instead of unity (1).

This screening test refers to an equation that overestimates the mean radioactivity concentration in a survey unit that contained an area of elevated radioactivity concentration. It is being omitted and replaced by more appropriate EMC screening tests for elevated measurements in final status survey data. The first EMC screening test will be whether any single measurement in final status survey data greater than AF x $DCGL_W$ occurs (where AF, the area factor, is read from its graph in §5 for an area = 10 m^2). The second EMC screening test will be whether the arithmetic mean of measurements within an identified area of elevated measurements is greater than AF x $DCGL_W$ (where AF, the area factor, is read from its graph in §5 corresponding to the delineated area of elevated measurements exceeding the $DCGL_W$). This revision is made in DP §14.4.3.8 ¶ "Elevated Measurement Comparison (EMC) Limit Screening."

In the event non-parametric statistical testing is unduly affected by area(s) of elevated measurements, an alternate method testing a survey unit may be appropriate. DP §14.4.3.9 "Contingencies" (separated from previous §14.4.3.8) is revised to provide for an alternate means of assessing compliance with release criteria. It provides for interpretation of the source term representing the survey unit and calculation of potential radiological dose using that source term in the same model used to derive the $DCGL_W$ in DP §5.

The proposed means to summarize final status survey data to interpret its fraction of the DCGL and a source term from which to calculate potential radiological dose in a survey unit are described hereafter. Explanation of deficiencies in the expression proposed in the MARSSIM follows.

Proposed Interpretation. *Radioactivity Concentration.* Mathematical modeling to estimate radiological dose attributable to residual radioactive material in a survey unit assumes uniform areal distribution of the source. The modeling also assumes potentially exposed person(s) move randomly within the survey unit, thereby equally likely to be exposed to any part of it. When either pertains, the best single-valued source of potential exposure and radiological dose would be the arithmetic mean of random, or unbiased measurements in the survey unit. If background is to be excluded, the arithmetic mean of reference area measurements would be subtracted from the survey unit mean concentration. By acknowledging that the arithmetic mean concentration in a survey unit is the best single-valued representation of the residual source, the MARSSIM[13] is in implicit agreement with assumptions of random movement by a receptor and that each measurement represents about the same fraction of the total survey unit area. That is, a person is equally likely to be exposed to each unit area within the survey unit.

Suppose residual radioactivity is elevated in local area(s) of a survey unit and that the areal density of elevated measurements is substantially greater than in the remainder of the survey unit. Estimation of potential exposure would need to account for the proportions of survey unit area represented by substantially differing measurement density; else the elevated measurement area(s) would overweight the arithmetic average as the best single estimate of radioactivity concentration. This may be done by employing the following expression.

$$F = \left(\frac{A_{EM}}{A_T} \times \frac{\bar{C}_{EM}}{AF \times DCGL_W} \right) + \left(\frac{1 - A_{EM}}{A_T} \times \frac{\bar{C}_{other}}{DCGL_W} \right) \quad \text{equation 1}$$

where

- F = exposure-weighted fraction of $DCGL_W$ presented by residual radioactivity in survey unit
- A_{EM} = area within which elevated measurements occur (m^2)
- A_T = total area in survey unit (m^2)
- $\bar{C}_{EM}$ = arithmetic mean radioactivity concentration in area of elevated measurements (pCi/g or dis/(min· 100 cm^2))
- AF = area factor for elevated measurements
- $\bar{C}_{other}$ = arithmetic mean radioactivity concentration in the survey unit area not containing radioactivity elevated > $DCGL_W$. (pCi/g or dis/(min· 100 cm^2))
- $DCGL_W$ = derived concentration guideline level (pCi/g or dis/(min· 100 cm^2))

The term, A_{EM}/A_T, represents the fraction of the survey unit area occupied by elevated measurements. The term, $(1-A_{EM})/A_T$, represents the remaining fraction of the survey unit area. The term, $C_{EM}/(AF \times DCGL_W)$, represents the fraction of the elevated measurements concentration criterion in the area of elevated measurements that the arithmetic mean concentration in that area represents. It also represents the fraction of the corresponding radiological dose limit, 25 mrem/yr, posed by occupancy within the area of elevated measurements. The term, $C_{other}/DCGL_W$, represents the fraction of the maximum acceptable average radioactivity concentration attributable to the mean radioactivity concentration in the remainder of the survey unit.

[13] MARSSIM Committee. *Multi-Agency Radiation Survey and Site Investigation Manual.* NUREG-1575. apx D. §D.5. Dec. 1997.

Assuming a person is equally likely to be exposed to each unit of area within a survey unit, A_{EM}/A_T also represents the fraction of time a person is exposed within area(s) of elevated measurements. $(1-A_{EM})/A_T$ also represents the fraction of time a person is exposed within the portion of the survey unit not containing elevated measurements. Thus, the overall fraction of $DCGL_W$ in the survey unit, weighted by exposure time in each portion, is represented by equation 1. The weighting by proportionate exposure time would also enable the equation to represent the fraction of the radiological dose limit corresponding to the $DCGL_W$.

Radiological Dose. If elevated measurements criteria are satisfied, but perhaps cause anomaly in statistical testing, potential radiological dose in the survey unit may be calculated with the same model used to derive $DCGL_W$. If so, the arithmetic average radioactivity concentration to be the source in the radiological dose calculation would be derived with the following equations.

$$\bar{C}_{SU} = \frac{A_{EM}}{A_T} \times \bar{C}_{EM} + \frac{1 - A_{EM}}{A_T} \times \bar{C}_{other} \qquad \text{equation 14-14}$$

where $\bar{C}_{SU}$ = arithmetic mean of radioactivity concentration measured at locations in survey unit. (pCi/g or dis/(min· 100 cm^2))

A_{EM} = area within which elevated measurements occur (m^2)

A_T = total area in survey unit (m^2)

$\bar{C}_{EM}$ = arithmetic mean radioactivity concentration in area of elevated measurements (pCi/g or dis/(min· 100 cm^2))

$\bar{C}_{other}$ = arithmetic mean radioactivity concentration measured at unbiased locations in the survey unit area not containing radioactivity elevated > $DCGL_W$. (pCi/g or dis/(min· 100 cm^2))

In the event radiological dose is to be exclusive of natural background radioactivity, the average background concentration would be subtracted from the survey unit average, $\bar{C}_{SU}$, to derive the net source term to enter into the dose model.

If the mean dose does not exceed the radiological dose criterion, compliance would be demonstrated for the survey unit.

<u>MARSSIM Equation 8-2</u>. *Radioactivity Concentration.* Another interpretation about how to account for localized area(s) of elevated measurements within a survey unit in which residual radioactivity is otherwise nearly uniformly distributed in the remainder of the survey unit is described in the MARSSIM[14] and in NUREG-1757.[15] It is expressed as a fraction of the $DCGL_W$.

$$\left(\frac{\delta}{DCGL_W}\right) + \left(\frac{\bar{C}_{EM} - \delta}{AF \times DCGL_W}\right) < 1 \qquad \text{MARSSIM equation 8-2}$$

[14] MARSSIM. §8.5.2.

[15] NUREG-1757, 2, apx A, §A.4.2.

where δ = arithmetic mean of radioactivity concentration measured at unbiased random or systematically distributed locations throughout a survey unit[16]

The first term, $\delta/DCGL_W$, accounts for all measurements in unbiased locations in the survey unit and thereby represents the average fraction of the $DCGL_W$ in the survey unit. If each measurement represents an equal portion of the survey unit area and if a receptor is assumed to roam at random throughout the survey unit, δ is an unbiased estimator of exposure to residual radioactive material; and only the first term is needed.

The numerator of the second term, $C_{EM} - \delta$, represents the average excess over the survey unit average radioactivity concentration. The denominator in the second term, AF x $DCGL_W$, represents the radioactivity concentration in a small area that would cause the maximum allowable annual exposure if a receptor were to remain in that small area during the entire occupancy time assumed in deriving the $DCGL_W$. Thereby, the second term gives equal weight to the excess residual radioactivity, *i.e.*, the net above δ, and to the survey unit average; whereas, the relative fraction of time a receptor would be expected to be in the smaller area of elevated concentration should be assumed to be in proportion to its fraction of the total survey unit area.

Thus, MARSSIM equation 8-2 would overestimate the average expected exposure to a person in a survey unit from residual radioactivity concentration in that the excess radioactivity concentration in an area of elevated measurements would be counted in both terms, and exposure time to the excess radioactivity in an area of elevated measurements would be overestimated in the second term.

35. In Section 14.4.3.8, page 14-27, it is stated "Construct a retrospective power curve of the measurements. Evaluate whether the survey unit would have passed the release criterion using the non-parametric statistical test, *e.g.*, WRS test. If not, it would be acceptable to make more measurements at random locations in the survey unit and perform statistical test(s) on the expanded data set." This is essentially double sampling and requires NRC concurrence prior to performing to make sure the probability of releasing a contaminated area is acceptable. Please add NRC concurrence is required.

Response:

Mallinckrodt would review data quality objectives, would notify the NRC Project Manager of intent to perform double or two-stage sampling in accordance with NUREG-1757[17] and would seek concurrence. In order to avoid delay of decommissioning activity, Mallinckrodt would expect NRC response within 4 business days. See also DP §14.2.

Specifying more measurements than estimated in §14.4.3.5 to be needed for population statistics should be acceptable in initial final status survey design and performance. Conceptually, adding more measurements at random locations in order to demonstrate statistical compliance should also be conceptually acceptable. That is, if an abundance of unbiased measurements, even if collected in two stages, demonstrates compliance, that

[16] MARSSIM. §D.5.
[17] NUREG-1757. apx A. §A.7.5 & apx C.

should be acceptable. Agency guidance[18] recognizes allowance may be made for a second set of samples to be taken if the retrospective power of the test using the first set of samples does not meet the design objective.

36. In Section 14.4.3.8, page 14-27, it is stated "Reverse the tested hypothesis and apply an alternate, appropriate statistical test, *e.g.,* from Scenario A to Scenario B. Specific DQO would be developed for this approach and be submitted to the NRC for approval, or would be addressed in the FSS report for survey units that fail." NRC concurrence should be obtained prior to using Scenario B. Please delete ", or would be addressed in the FSS report for survey units that fail".

   Response:

   Statistical testing of a population of measurements by alternate hypotheses identified as Scenario A and Scenario B is given about equal credence and explanation of application in NRC report NUREG-1505.[19] MARSSIM considers both Scenarios.[20] When regulated radionuclides are also in natural background (*e.g.,* source material), background variability is relatively large, and $DCGL_W$ is relatively small, Scenario B may be more able to distinguish the regulated material from background at $DCGL_W$, and thus be more useful than Scenario A.

   Nevertheless, in the event Mallinckrodt were to decide to assess compliance using Scenario B, it would notify the NRC Project Manager to seek concurrence and, to minimize delay, would expect (dis)approval or any question(s) within 4 business days before implementation. CT 2 DP §14.4.3.9 (previously §14.4.3.8) is being revised to indicate this intent.

37. In Section 14.4.3.8, page 14-27, last bullet, it is stated "In lieu of statistical testing, compute the radiological dose associated with the mean of measurements in the survey unit. Alternatively, compute the radiological dose attributable to each measurement as if it represented the entire survey unit and calculate the arithmetic mean dose represented by all the measurements in the survey unit. If the mean dose does not exceed the radiological dose criterion, compliance would be demonstrated for the survey unit." The mean dose being less than the radiological dose criterion is a necessary condition for compliance but not a sufficient condition. Delete the last bullet.

   Response:

   Mallinckrodt agrees that mean dose being less than the radiological dose criterion is a necessary condition for compliance but not a sufficient condition. Independently of the provision cited in Section 14.4.3.8, page 14-27, last bullet (now changed to §14.4.3.9), if an elevated measurements criterion stated in §14.4.3.8 ¶"Elevated Measurement Comparison (EMC) Screening" is not also satisfied, a survey unit may not be released. Final status survey data are subject to other tests in §14.4.3.8 separately from comparison of population

[18] NUREG-1757. apx A. §A.7.5.

[19] Gogolak, C.V., *et.al., A Nonparametric Statistical Methodology for the Design and Analysis of Final Status Decommissioning Surveys.* NUREG-1505.

[20] MARSSIM. apx D. p. D-17.

statistics and $DCGL_W$. Calculation of radiological dose is an alternative only "If a non-parametric statistical test is failed,..." as posed on DP page 14-27.

NRC guidance recognizes two approaches to assessing compliance with the radiological dose criterion. They are 1) radiological dose assessment by modeling or 2) development of DCGL by modeling and final status survey to assess compliance.[21] "Calculating the final dose is the most direct approach to show compliance with Subpart E's dose criteria."[22]

The bullet in question relates radiological dose assessment as an alternative to statistical testing of a population of measurements in a survey unit, *i.e.*, in lieu of non-parametric statistical testing to evaluate compliance with $DCGL_W$. It is not intended to apply to elevated measurements for which testing of compliance is specified elsewhere. With that recognition, the survey unit mean dose attributable to residual source being less than the radiological dose criterion should also be sufficient to satisfy the function served by WRS testing to assess whether a population of measurements representing a survey unit complies with the $DCGL_W$. Furthermore, if this contingency is taken, the same modeling used to derive the $DCGL_W$ would be used. The residual source would be interpreted from final status survey data as described in response to item 34 herein.

38. The statement is made on page F-3 that "instrumentation used in the field is practically the same as used in a counting room". However, the counting room instrumentation appears to be high-purity germanium (Table 14-2 p. 14-6), while the field instruments are sodium iodide. In general, these will not have comparable lower limits of detection. Clarify the types of instruments to be used in the counting room and the field. In addition, a commitment should be added to supply the NRC with a technical basis document, prior to use, for in-ground gamma spectroscopy.

    Response:

    Typical instruments used in field surveys are listed in DP §14.4.1 Table 14-1. Typical instruments used in counting room measurements are listed in DP §14.4.1 Table 14-2. In the event a contractor proposes other instrumentation, it must meet quality objectives for calibration, detection capability, and operability.[23]

    DP Appendix F, "Radionuclide Analysis in Soil by In-ground Gamma Spectrometry," describes a method and instrumentation that is adequate either in-ground or in a counting room. In the event in-ground gamma spectrometry is used in surveys of record, as represented in response to item 14, we are agreeable to developing a technical basis document demonstrating the in-ground gamma spectroscopy instrumentation and method meet quality objectives. The document will be developed before the instrumentation is used and will be available on-site for NRC inspection. To aid in prospect of timely use, availability of the technical document for inspection would be preferable to submittal to an NRC office.

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[21] NUREG-1757. 2. §2.5.

[22] NUREG-1757. 2. §2.5.1

[23] CT 2 DP, §14.4.1. "Instrumentation."

A favorable attribute of a high-purity germanium detector is high-resolution of gamma rays and characteristic X-rays to enable identification of radionuclides. When the suite of key radionuclides is known that attribute diminishes in importance. At natural background concentration of uranium series and thorium series, lower limit of detection is important. Energy resolution aside, an NaI(Tl) detector of practical size, *e.g.*, 2 x 2 inches or larger, is as sensitive as a germanium detector of practical size. In the event that key U-series and Th-series radionuclides are proposed to be measured in-ground by NaI(Tl) detector-gamma spectrometry, demonstration of adequate lower limit of detection will be documented. If earlier description of the method might be useful, a meeting to discuss it may be most efficient.

39. Page "Attach 1-4" describes the results of RESRAD modeling of occupational dose for workers. Will construction workers be trained as radiation workers so that the occupational dose limits apply? If not, the statement "The estimated annual dose to the construction worker is less than 10% of the basic radiation dose limit." is not true. Please clarify if construction workers will be trained as radiation workers.

    Response:

    Construction workers performing decommissioning will be trained as radiation workers commensurate with the radiological dose and risk estimated and observed. Radiation safety training program description in DP §9.4.2 is being revised to include this specification.

    The estimate in Attachment 1 of potential, annual radiological dose to a remediation worker is but 20 mrem/yr above the standard for a member of the public. The accident analysis in Attachment 2 also estimates similarly low potential dose in an acute, accidental exposure.

    While we have prudently planned that remediation workers be considered radiation workers, only a modest radiation protection program would be needed to assure the low exposures estimated. According to Attachments 1 and 2, a modest program would be justifiable and sufficient to assure potential exposures are As Low As Reasonably Achievable.

40. Appendix E, Section E.1.1.6, references Tables 4-1 and 4-2. The correct tables to reference are Tables 14-1 and 14-2.

    Response:

    Reference to Tables 4-1 and 4-2 in Appendix E, Section E.1.1.6 will be revised to refer to Tables 14-1 and 14-2.

EPAD INQUIRIES

41. (a) The thickness of the contaminated zone: The licensee selected a thickness of 2 m (RESRAD default value) to represent the contaminated area across the site. However, borehole data showed that the thickness varies from 0.01 to 4.5 m. Albeit that the average thickness may correspond to 2 m; this parameter could be better represented as variable with a distribution between these two limits. Alternatively, the licensee may conduct a sensitivity analysis to demonstrate that a source thickness of more than 2m will not have any significant influence on the dose result.

    Response:

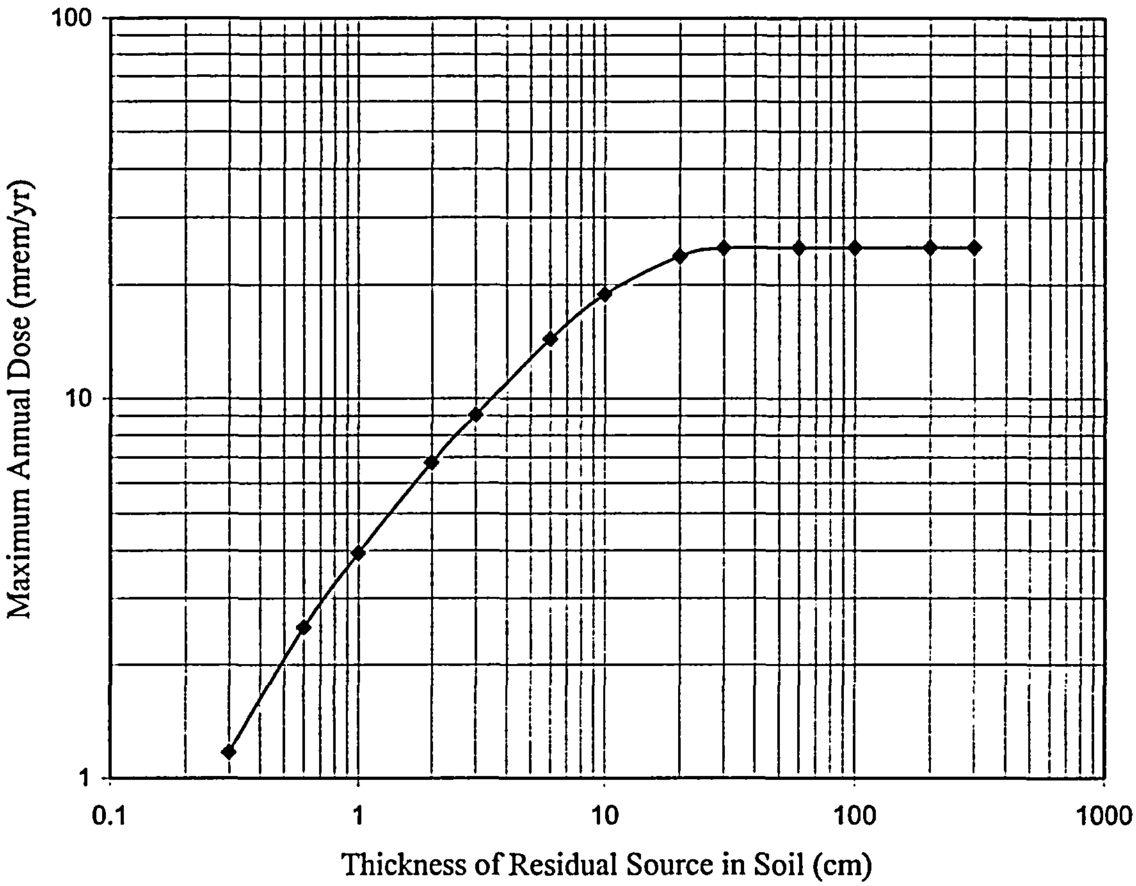
    An analysis of the effect of contaminated zone thickness on radiological dose during industrial land use has been performed. It interprets the depth beyond which additional contribution from a representative source in soil to irradiation dose to a person becomes negligible. Essential features of modeling to perform this analysis were:

    - a reasonably representative source ratio of 3 U series, 0.0455 x 3 actinium (U^{235}) series, and 1 Th series together. (Total source concentration at this ratio was entered into RESRAD to produce a baseline radiological dose rate = 25 mrem/yr at infinite source thickness.);
    - bare land in which residual source contamination extends from land surface downward into the soil;
    - indoor time fraction = 0.0 in order to simulate effect of irradiation on bare land;
    - the same industrial land use scenario modeled to derive $DCGL_W$ originally, except absent ingestion of soil and inhalation of dust; (for the origin of inadvertently ingested dust and of dust suspended into air is surficial topsoil); and
    - deterministic simulation using RESRAD to derive the effect of increasing contamination depth in soil on exposure to direct irradiation.

    The result of this analysis is summarized graphically in Figure 41. It determined that, in representative simulation, maximum dose rate by direct irradiation is reached asymptotically as the depth of the contaminated zone in topsoil reaches about 30 cm. Additional source thickness would not produce significantly greater dose rate.

    This evaluation of the merit of our original modeling representing source thickness has demonstrated that the original basis of 2 meters source depth was exceedingly conservative in modeling dose and deriving DCGL. Nevertheless, we will represent the thickness of contaminated zone parameter as a variable in probabilistic modeling. It is being represented as a uniform distribution ranging from 0 to 1 meter thick. It is being represented as a uniform distribution because characterization survey soil sampling intervals are insufficient to resolve a well-defined gradient within this range. A maximum depth of 1 meter is more than sufficient to be a conservative representation insofar as direct irradiation is concerned.

Figure 41. Maximum Annual Radiological Dose Versus Source Depth in Soil (infinitely-thick source ratio 3 U series + 1 Th series produces 25 mrem/yr)



42. (b) The mass loading for inhalation factor: the licensee used a factor of 3.500E-05 g/m^3 for the industrial worker scenario and a factor of 8.0E-05 g/m^3 for the construction/excavation worker scenario. The RESRAD default value is 1.00E-04 g/m^3. The licensee used references with ranges of mass loading factor. Since the value for this sensitive parameter is uncertain, this parameter could be better represented as variable with a distribution between the two limits 5.0E-04 and 2.3 E-05 g/m^3. Alternatively, the licensee may select a more conservative value to bound the variable site conditions within the 1000 years performance period.

Response:

The model of radionuclides in outdoor air of respirable size subject to inhalation is the product of the radionuclide concentration in surface soil and the airborne density of particulates of respirable size in ambient air. Biwer, *et.al.*,[24] summarized the distribution of respirable particulate in ambient air reported by the EPA[25] for about 1790 air monitoring stations in a range of environments. At cumulative probability = 0.50, the most frequent respirable particulate density in the EPA distribution occurs at about 23 μg/m^3 air.[26]

Three other sources of data were examined to get more comprehensive information about airborne particulate density in urban air. The total mass loading of airborne dust in an urban area has been estimated to range from 60 to 220 μg/m^3 by USHEW[27] and 33 to 254 by Gilbert, *et.al.*[28] Their respective geometric means are approximately 115 and 92 μg/m^3. Airborne particulates measured in 14494 urban and 3114 non-urban air samples in the National Air Sampling Network exhibited a geometric mean of 98 μg/m^3.[29] A best geometric estimate of those is about 102 μg/m^3.

Estimation of intake by inhalation depends on the airborne concentration of contaminated airborne particulate matter, *i.e.*, soil, that is respirable. About 0.28 to 0.33 of airborne particles have been found to be respirable, *i.e.*, less than 10 μm in diameter.[30, 31, 32, 33] The mass loading of respirable particulate in air may be estimated as the product of the total mass loading of airborne dust and the respirable fraction. Thus, a reasonable estimate of the geometric mean of respirable mass loading for inhalation in an urban, industrial area is about 0.3 x 102 μg/m^3 = 31 μg/m^3.

A distribution representing airborne particulate loading in urban air may be estimated by the shape of the distribution in NUREG/CR-6697, Table 4.6-1 and Figure 4.6-1, shifted upward by an increment representing the increase in dust in urban air relative to all ambient air. The result, in Figure 42, becomes the probabilistic distribution to replace the default distribution in RESRAD v. 6.22. This distribution represents careful, reasonable appraisal of values of airborne respirable mass loading in an urban environment. Derivation of $DCGL_W$ in soil are being derived by probabilistic modeling using this distribution of respirable particulate density in air.

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24 Biwer, *et.al.* "Parameter Distributions for Use in RESRAD and RESRAD-BUILD Computer Codes." atch C, pp. C4-15 & C4-16 in NUREG/CR-6697. Dec. 2000.

25 USEPA. Aerometric Information Retrieval System. internet site http://www.epa.gov/airs/airs.html. 1999.

26 Biwer, *et.al.*, Table 4.6-1 and Fig. 4.6-1 in NUREG/CR-6697.

27 USHEW. *Air Quality Criteria for Particulate Matter.* 1969. in NUREG/CR-5512, 1, p. 6.11.

28 Gilbert, T.L., *et.al.*, *Pathways Analysis and Radiation Dose Estimates for Radioactive Residues at Formerly Utilized MED/AEC Sites.* ORO-832 rev. Jan 1984. in Yu, C. *et.al.*, *Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil.* ANL/EAIS-8. pp. 110-111, Apr. 1983.

29 Stern, A.C., ed. *Air Pollution.* 2nd ed. Academic Press. NY. 1968.

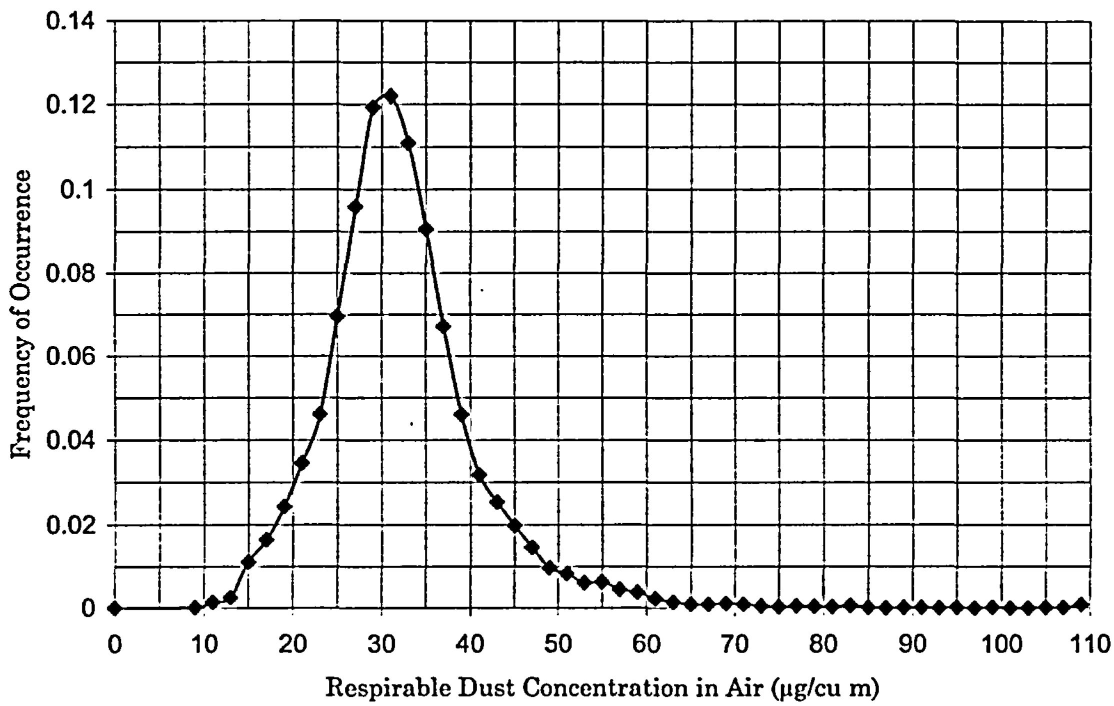
30 USEPA. *Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment.* EPA 520/4-77-016. pp. 31-32. Sept. 1977.

31 Chepil, W.S., "Sedimentary Characteristics of Dust Storms: III Composition of Suspended Dust." Am. J. Sci., 225, p. 206, 1957. in EPA 520/4-77-016, p. 57

32 Sehmel, G.A., *Radioactive Particle Resuspension Research Experiments on the Hanford Reservation,* BNWL-2081, 1977.

33 Willeke, K. *et.al.*, "Size Distribution of Denver Aerosols - A Comparison of Two Sites," Atm. Env., 8, p. 609, 1974.

Figure 42. Frequency Distribution of Respirable Dust in Urban Air
(EPA AIRS PM-10 data normalized to urban environment)



43. (c) The licensee selected an indoor gamma shielding factor of 0.17. In other words the licensee assumed that only 17% of outdoor gamma radiation can be penetrated indoors. The RESRAD default value is 0.7. The licensee indicated that Plant 5 has concrete slab floors or concrete walls with few windows. Therefore, the licensee assumed that the factor 0.17 should represent the gamma shielding for the building flooring and walls. It should be noted that the performance period for decommissioning is1000 years. Therefore, the assumption that concrete floors and walls will be always available and well maintained to shield from gamma radiation is unrealistic. For example, prefabricated buildings may be constructed on the contaminated soil with minimum shielding from walls and floors. Further, a security guard may be located at the entrance of the building with much less shielding from outdoor gamma radiation. It should be noted that the shielding factor for the construction worker was conservatively selected as 1.0; however, the shielding factor for the industrial worker scenario is not well justified. This important sensitive parameter could be better represented as variable with a distribution between the two limits 0.17 and 0.7. Alternatively, the licensee may select a more conservative value for the shielding factor to bound potential site-specific conditions within the 1000 year performance period.

Response:

DCGL are being revised to include the effect of probabilistic distribution of indoor gamma shielding factor.

While dose analyses would still be projected for 1000 years, recent NRC staff view is to allow justification of scenarios based on the reasonably foreseeable future instead of any viable land use envisioned during the next 1000 years.[34] The "reasonably foreseeable future" would be based on what land uses are likely within a time period of the next few decades to about a hundred years. Current NRC position would focus land-use scenarios on 1) the nature of the land and reasonable predictions based on its physical and geologic characteristics and 2) societal uses of the land based on past historical information, current uses, and what is reasonably foreseeable in the future. Primary justification for scenarios would be related to physical features of the site, radionuclide half-life, and time of peak exposure.

Industrial buildings have a finite, useful lifetime and are assumed to be replaced in kind instead of assuming maintenance for 1000 years. Physical and geological characteristics of the cinder fill and current and past engineering practice have caused Mallinckrodt to construct concrete slab on grade floors in its buildings. While alternate construction is conceivable, concrete slab flooring is and will continue to be what is reasonably foreseeable in industry. An estimate of the most likely distribution of concrete slab floor thickness in the foreseeable future is in Table 43.

An analysis of the effect of radiation attenuation by a building, especially floor thickness, on radiological dose for the portion of time a worker spends indoors during industrial occupation has been performed. Essential features of modeling to perform this analysis were:

- a reasonably representative source ratio of 3 U series, 0.0455 x 3 actinium (U^{235}) series, and 1 Th series together;
- residual source contamination extends from land surface downward one meter into the soil;
- outdoor time fraction = 0.0 in order to simulate effect of irradiation indoors;
- the same industrial land use scenario modeled to derive $DCGL_W$ originally, except absent ingestion of soil and inhalation of dust; (for the origin of inadvertently ingested dust and of dust suspended into air is surficial topsoil);
- deterministic simulation using RESRAD to derive the fraction of gamma dose rate as a function of concrete floor thickness [ref. Figure 43A]; and
- combination of probable distribution of floor thickesses and indoor gamma shielding factor to derive a probability distribution of indoor gamma shielding factor.

On the premise that a floor construction is likely to be specified in an integer thickness in units of inches, a *discrete cumulative* probability distribution of these data has been specified in RESRAD. Figure 43A summarizes the fraction of dose rate from gamma radiation penetrating a concrete floor as a function of its thickness. Figure 43B depicts the cumulative probability and indoor gamma shielding factor data entered into RESRAD for probabilistic evaluation of the effect of this parameter on radiological dose rate.

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[34] NRC. "Results of the License Termination Rule Analysis." SECY-03-0069. May 2, 2003.

Figure 43A. Fraction of Gamma Dose Rate Penetrating a Concrete Floor
source ratio: 3 U series + 0.1365 U235 series + 1 Th series; one meter deep in soil

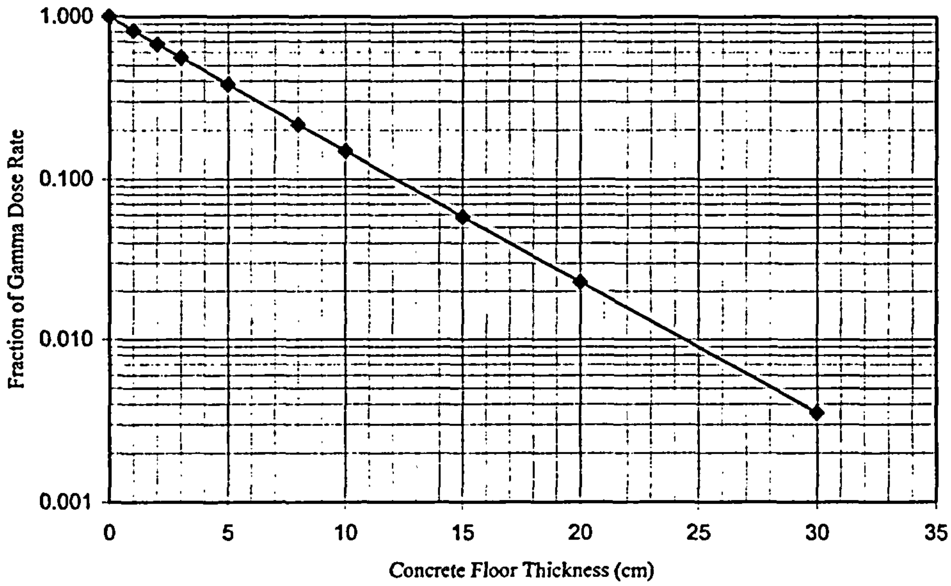
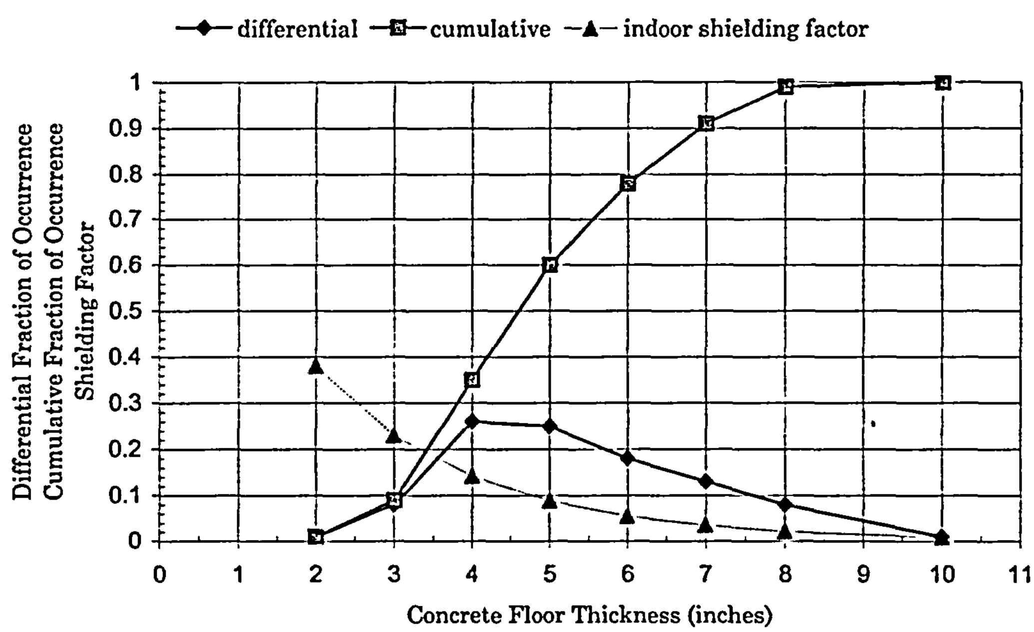


Figure 43B. Indoor Gamma Shielding Factor Distribution



The result of this analysis is summarized in Table 43 where the indoor gamma shielding factor probability distribution is tabulated. RESRAD modeling estimates the time of peak exposure occurs now or in the near future.

Table 43. Indoor Gamma Shielding Factor Distribution

Floor Thickness (inches)	Floor Thickness (cm)	Fraction of Occurrences	Indoor Gamma Shielding Factor (fraction penetrating floor)
2	5.1	0.01	0.38
3	7.6	0.08	0.23
4	10.2	0.26	0.14
5	12.7	0.25	0.088
6	15.2	0.18	0.055
7	17.8	0.13	0.035
8	20.3	0.08	0.022
10	25.4	0.01	0.0084

This indoor gamma shielding factor distribution will be entered into RESRAD as a discrete cumulative probability distribution of the variable, *external gamma shielding factor*, during indoor occupancy.

44. (d) The Occupancy Time: The licensee selected for the industrial worker scenario an occupancy time of 0.1825 for indoors and 0.04566 for outdoors. These factors should be acceptable because they are based on an estimated 2000 working hours per year. The occupancy time for the construction worker scenario, however, was selected based on 80 working hours per year corresponding to a time fraction of 0.0081 expended outdoors. The 80 hours occupancy time may be limited to a certain construction worker doing excavation at the site. However, construction workers may conduct other activities besides excavation and may perform renovation activities. NUREG/CR-5512 Vol. 1 considered an occupancy time for building renovation of 8 h/d , for a total exposure period of 90 days. This time period corresponds to 28.3 days on the job which is equivalent to 0.057 time fraction for the year. However, for this scenario a fraction of this time should be expended indoors. Therefore, the occupancy time fraction for the construction worker scenario may be considered in two parts, an outdoor time fraction of 0.0081 and an indoor time fraction of 0.041. Because this parameter is uncertain, a distribution of occupancy parameter for outdoor could be represented in the range 0.008 - 0.041 and for the indoor in the range of 0.0 - 0.041. If the licensee prefers to exclude this scenario from the analysis and preferably use

conservative assumptions and parameters for the industrial worker scenario this issue may be disregarded.

Response:

$DCGL_W$ and $DCGL_{EMC}$ applicable to soil are based on the industrial worker scenario, which is more constraining than the construction worker scenario. The construction worker scenario was evaluated and described for completeness.

This staff comment indicates that industrial occupancy time fractions of 0.1825 indoors and 0.04566 out-of-doors should be acceptable inasmuch as they combine to the equivalent of a 2000-hour work-year. We would propose to retain these single-valued estimates in dose modeling. They are not likely to underestimate the occupancy time of an industrial worker in Plant 5. For by comparison, the USACE estimated industrial worker occupancy 0.1969 of time indoors and 0.04566 out-of-doors on nearby Plant 2;[35] while the ANL staff estimated industrial worker occupancy indoors to be 0.17 of the time and occupancy out-of-doors to be 0.06 of the time.[36]

Industrial worker occupancy is prominently greater than that of a construction or utility worker, especially since outdoor construction or utility work is likely to be done intermittently by contract labor. In view of less occupancy in the construction work scenario, and in view of commentary in this RAI, the construction, or utility, work scenario in CT Phase II Decommissioning Plan, §5.8.2 is being omitted from further consideration.

45. (e)Derivation of radionuclide specific $DCGL_w$ based on the radionuclide Guideline (G(i,t) at the time of the total peak dose. The licensee presented the $DCGL_w$ for each specific radionuclide (Table 5-1, page 5-3) based on the guidelines (e.g., radionuclide concentration equivalent to 25 mrem/y) at the time of the peak dose($G(i,t_{peak})$ of the overall radionuclides in the three decay series. This approach is no-conservative and contrary to the recommendation of NRC Guidance in NUREG-1757, Vol. 2, Section 2.7. When using the sum-of-fraction approach to establish the radionuclide specific DCGLs the licensee should select the conservative radiuonuclide specific guideline limit at the minimum single radionuclide soil guideline ($G(i,t_{min})$). Therefore, using NUREG-1757, Vol. 2 recommendations, the radionuclide specific DCGLs would change significantly. For example, The Th-232 DCGL using the $G(i,t_{peak})$ was derived at 394.9 pCi/g, whereas the Th-232 DCGL using the $G(i,t_{min})$ would be 20.77 pCi/g. The licensee should explain further and justify selection of these radionuclide specific DCGLs assuming that the sum-of-fraction principle would be applied. Alternatively, the licensee may clarify that the radionuclide sum-of-fraction approach will not be used in the demonstration of compliance with the dose criteria.

[35] USACE. Post-Remedial Action Report for the St. Louis Downtown Site Plant 2 Property. Table B-3. June 2001.

[36] Yu, C., *et. al.*, ANL/EAD-4, Table 2-3, p. 2-22.

Response:

Mallinckrodt believes that the approach used to calculate the DCGLws is consistent with NRC guidance[37], is not non-conservative, and does meet the requirements of 10 CFR Part 20, Subpart E. This position is discussed in more detail in Appendix 45 herewith.

NRC guidance[38] recognizes that when separate radionuclides produce peak dose at separate times, a sum-of-fractions based on DCGLs derived independently of each other would overestimate the dose and fraction of the dose limit posed by their combination. Guidance documents also recognize that, in the presence of multiple radionuclides, the DCGLs need to be adjusted to account for the presence of the multiple radionuclides contributing to the total dose[39] or else the dose may be calculated on the basis of survey data.[40] If DCGLs are to be adjusted, guidance[41] states, "Due to the additive nature of the dose from each radionuclide, the total residual activity must be proportionally reduced to ensure the sum of each radionuclide divided by its DCGLw does not exceed one (unity)." This emphasizes the collection of radionuclides comprising the source and that, altogether, their sum-of-fractions is not to exceed one. Thus, when the source includes multiple radionuclides, the guidance does not require the impossibility of compositing doses into one year that actually occur in separate years.

$DCGL_W$ in C-T Phase II Decommissioning Plan, §5, Table 5-1 were derived on the basis of dose rate factors at the time of maximum total dose potentially caused by a mixture of uranium series, actinium series, and thorium series radionuclides that produces the maximum total annual dose. Additional calculations reported in Appendix 45 herewith demonstrate that applying $DCGL_W$ derived on the basis of maximum total dose rate would not allow non-conservative residual concentration in topsoil for the range of radionuclide mixtures reasonably expected in C-T decommissioning. The evaluation includes derivation employing the sum-of-fractions of $DCGL_W$ of constituents among a range of reasonably expected relative distributions, *i.e.*, radionuclide spectra. It also includes confirmatory calculation of maximum annual dose posed by example sources at the $DCGL_W$ derived by the sum-of-fractions convention.

In the event peak doses from different radionuclides occur at different times, NRC guidance[42] provides that a licensee may compute the combined dose using concentrations determined by the final status survey. With equivalent result, we have derived dose factors and DCGL for the range of concentrations of radionuclides observed in extensive characterization survey summarized in CT Phase II DP §4. That derives the maximum, or peak, dose in future time for the uranium series, actinium series (U^{235}), and thorium series relative concentration mix that may remain after remediation. Applying $DCGL_W$ derived in this way satisfies the intent of the NRC guidance and would not allow non-conservative residual concentration in soil for the range of radionuclide mixtures reasonably expected in C-T decommissioning. Whereas, applying dose factors and DCGL derived for each

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37 NRC. Consolidated NMSS Decommissioning Guidance. NUREG-1757, 2, §2.7.
38 NRC. NUREG-1757, 2, §2.7.
39 MARSSIM, §4.3.3.
40 NRC. NUREG-1757, 2, §2.7.
41 NRC. NUREG-1757, 2, apx O, §O.3.4.2.
42 NRC. NUREG-1757, 2, §2.7.

radionuclide independently, with some dose factors maximized at differing future times, would be burdensomely and unnecessarily overly-conservative by more than a factor of 2, as is demonstrated in Appendix 45, §7.

Having extensive characterization survey data, calculating potential radiological dose for that relevant range of residual radionuclide sources in soil determines the maximum total dose and a corresponding set of DCGL. Adopting that set of DCGL will provide reasonable assurance that total dose from any spectrum of radionuclides to be encountered after remediation will not exceed the 25 mrem/yr criterion during any future year when controlled by using those DCGL in the unity rule. Since none of the combinations of sources [ref. Tables 1 and 11] enveloping those observed during extensive characterization survey yields DCGLw greater than proposed in CT 2 DP §5, Table 5-1, those proposed DCGLw, applied in sum-of-fractions for the uranium series and thorium series present, reasonably assure the 25 mrem/yr criterion will be satisfied.

Statements in NRC guidance[43] indicate that site specific analysis using realistic dose modeling can be used to calculate DCGLs. Mallinckrodt is confident that it has sufficient site characterization survey data and has done sufficient dose modeling in an approach that is consistent with guidance in NUREG-1757 to demonstrate that the DCGL proposed in CT 2 DP §5, Table 5-1, meet the intent and requirements of NUREG-1757.

46. (f) The licensee did not explain the basis for release of the contaminated sewers (if contamination of drains is identified in Phase I) and the scenario to be used for derivation of the DCGLs and related computations. For example samples taken from manholes #2, #34, #42, and #4 show significant contamination levels. The licensee should explain if the DCGLs for soil would also be used for release of contaminated sewer systems. Staff may find that the soil DCGLs could be appropriate as well for the sewerage system. However, the licensee needs to address this issue through consideration of other potential exposure scenario appropriate for the sewerage source.

Response:

In essence, contaminated sewerage near C-T process Building 238 will be plugged or will be removed during remediation of subsoil beneath Building 238. If sewerage is removed, the debris and sludge will be treated as potential radioactive waste. If plugged to prevent future use and left in place, the remaining sewerage and sediment will be considered part of the subsoil unit in which they are located. Other affected sewerage downstream will be subject to final status survey. Sediment in sewerage remaining is considered like subsoil at the equivalent depth interval.

As explained in CT 2 DP, §14.4.3.7, average concentrations of radionuclides in soil over one meter intervals (0-to-1 m, 0-to-2 m, 0-to-3 m, *etc.*, down to and including the sampling cutoff layer specified in DP §14.4.3.5) will be determined by core sampling and or in-borehole measurements to test compliance with $DCGL_W$.

Planned decommissioning activities concerning sewerage are described in DP §8.4. DP §14.4.3.2, provides the following information concerning final status survey of sewerage.

[43] NRC. NUREG-1757, 2, §2.5.2.

As described in Section 8 of the Phase II Decommissioning Plan, main sewer lines immediately to the west and north of Building 238 will be removed or plugged in the process of remediation of subsurface soils beneath Building 238.) If the sewers are plugged, the sewers and their contents will be considered for FSS purposes a part of the subsurface survey unit in which they are located. If they are removed, the sewers and the sludge in them will be treated as potential radioactive waste, as described in Section 12 of the Phase II Decommissioning Plan.

Sediment in sewers remaining in use downstream of Building 238 extending to the Waste Water Treatment Basin area and other sewers in the Plant 5 area will be considered a separate Class 3 survey unit. For classification and evaluation purposes, this sediment is considered no different from other subsurface soil at the equivalent depth. At each location, a single vertical average radionuclide concentration (as described in Section 14.4.3.1) in the sewer sediments and in soils located between the ground surface and the sewer, all taken as combined, has been used to establish the basis for comparison to limits for classification, and will be used for FSS evaluation.

The sewerage involved is clay or concrete composition, is buried in ground, and would be impractical to salvage intact. If future excavation were to intrude into it or even intend to remove it, one would expect it to be broken into debris during excavation. While being excavated and brought to the surface, the debris and nearby excavate would be expected to be mixed as excavation spoil. This is equivalent to the scenario in which inadvertently excavated subsoil would be mixed as excavation progresses from land surface downward, and the resulting mixture average concentration would be compared with $DCGL_W$ derived for topsoil. Thus, the appropriate scenario and model on which to derive $DCGL_W$ would be the same as for soil.

47. (g)The licensee indicated that the wastewater basins in Plant 7 (e.g., the wastewater neutralization basins located outside Plant 5) supported the C-T operations; therefore, it will also be decommissioned under the C-T DP II. The licensee provided in Table 4-5 showing that surface contamination (dpm/100 cm^2) of the wastewater neutralization basin did not exceeded the DCGLw. Table 4-5 did not show any data of volumetric contamination. In other words, the licensee appears to assume that only surface contamination is expected at the wastewater neutralization basin. The licensee should explain the basis for assuming only surface contamination may be present at the wastewater neutralization basin rather than volumetric contamination. The licensee needs to verify this assumption through sampling data on the depth of contamination at the basin. It should be noted that the assumption that the integrity of the lining material has been maintained over all the years of operation may not be sufficient to assume superficial surface contamination at the basin.

Response:

Characterization survey measurements on neutralization basin concrete surfaces are less than 0.1 $DCGL_W$ proposed for outdoor surfaces. [ref. DP Figure 4-5]. When doing final status survey of the basins, we will treat them as Class 2, will scan at least 0.1 of their area, and will do judgment measurements searching for evidence of embedded residual source material. If evidence of embedment or penetration into the concrete is discovered, we will investigate by scabbling or chipping into the concrete and or other convincing measurement. Else, if the final status survey passes without evidence of embedment into concrete, we will have reasonable confidence embedment has not occurred. CT Phase II Decommissioning Plan, §14 "Facility Radiation Surveys," is being revised to state this intent.

48. (h) Assumptions for the Industrial Worker Exposure to Pavement: For the exposure of industrial worker to residual radioactivity on pavements, the licensee made similar assumptions as those for the soil. However, the licensee assumed a thin layer of surface contamination on pavement with thickness of 0.1 cm. The licensee modified the approach to convert volumetric dose analysis results into surface activity results (e.g., dpm/100 cm^2). This was done through derivation of the radionuclide volumetric dose factor (mrem/y per pCi/g), converting this factor into areal density factor pCi/100 cm^2 (e.g., by assuming a thickness of pavement of 0.1 cm and a density of 1.5 g/cm^3) corresponding to 25 mrem/y and then converting the pCi into dpm (e.g., by multiplying by 2.22). Therefore, considering the volumetric dose analysis approach the following parameters and assumptions were made for industrial worker exposure to the pavement source: (i) Contaminated Zone: the licensee assumed that 0.1 cm thickness of soil adequately represents areal contamination on pavement. This is less conservative than the 2 m thickness assumed for the exposure to soil; (ii)The erosion rate for the pavement was assumed to be zero.

The licensee needs to verify that contamination only exist in a pavement medium of 0.1 cm thickness and no contamination below this thin crust of the pavement. In addition, by assuming an erosion rate of zero the licensee assumed that the pavement would be maintained through a performance period of 1000 years. The licensee needs to verify these assumptions and provide data and a rationale that the thin pavement layer would be maintained over a 1000 year time-frame.

Response:

Modeling Exposure. In the outdoor environment of interest, the potential exposure pathways would mainly be by direct gamma irradiation, inhalation of dust suspended into air, and ingestion of dust. Among these, the model simulating suspension of dust into outdoor air in RESRAD is appropriate; whereas the indoor ventilation model in RESRAD-BUILD would be less adaptable. The conceptual models for ingestion and inhalation in RESRAD are a function of radioactivity concentration in the surface dust or soil and not on its depth. Consequently, RESRAD was employed because it would be preferable for exposure to an outdoor source on pavement via these pathways.

Compatibility of Areal DCGL on Pavement and Mass DCGL in Soil Beneath. When considering derivation of DCGL, one factor is whether exposure to pavement and to soil beneath are independent. The near independence of exposure to pavement and soil is answered in response to item 4 herein. In essence, the scenario of exposure to bare soil, on which DCGL for soil were derived, and the scenario of exposure to pavement, on which DCGL for pavement were derived, cannot occur simultaneously. Absent pavement, exposure pathways to pavement are absent, and exposure to topsoil can occur. Thus, DCGL derived for soil are independent of presence of or contribution from pavement. Pavement would exist atop soil. When so, it would be a complete barrier against airborne and ingestion pathways of exposure to conceivable residue in the soil and an incomplete shield against gamma radiation penetrating from conceivable residue in the soil beneath. Resolution of item 4 herein also compensates for and effectively uncouples this dependence.

By this logic, it is not essential that pavement be maintained 1000 years without erosion. For if pavement were to erode or be removed, so would source on or embedded in the pavement be removed.

If the inventory corresponding to the areal $DCGL_W$ derived for the surface of pavement were embedded or migrated downward into pavement, the dose would diminish because of internal shielding of gamma radiation by pavement material. The inventory to be allowed on pavement surface corresponding to the areal $DCGL_W$ proposed in Table 5-3 would be less than inventory in about 6 cm of topsoil at the $DCGL_W$ specified in Table 5-1. (Tables now identified as Tables 5-4 and 5-3)

Areal DCGL on Pavement or Building Floor Slab. Whereas, a comment seeks justification of 0.1 cm thickness of residual source contamination on pavement, the objective in dose modeling was to determine the maximum **areal density** of contaminant on or near the surface that would not cause more than 25 mrem/yr.

RESRAD models simulate exposure to a source originating as a mass concentration in soil.[44] In order to simulate surficial contamination on pavement out-of-doors, a mass concentration equivalent of areal density of source material on pavement needs to be estimated. Assumption of 0.1 cm source thickness is sufficient for contamination of worker hands or clothing and potential for ingestion and removal from the surface to become suspended in air for potential inhalation. That is, modeling removal for either ingestion or inhalation pathways does not depend on a thicker source.

A common sense perspective on the assumption of 0.1 cm source thickness on pavement in Plant 5 may be realized by estimating the volume it would occupy. That volume would be 30 cubic yards, or three 10-cubic-yard, semi-trailer truck loads. Even if 2/3 of Plant 5 pavement were vacuum-cleaned (the remaining area occupied by structures), it would be quite unrealistic to expect to accumulate as much as two 10-cubic-yard, semi-trailer truck loads of sediment on the pavement remaining from more than 15 years ago.

Another expressed concern is whether contamination might be beneath, or deeper than, the assumed 0.1 cm thick surface contamination. Again, the pertinent objective is to derive the maximum acceptable average areal density, or $DCGL_W$, in units pCi/100 cm^2 or dis/(min· 100 cm^2) of surficial contamination, regardless of its depth of embedment.

To examine this issue, modeling has been done assuming residual U and Th series as a function of source thickness or embedment into pavement. The objective is to derive the maximum areal density of CT residue **on or embedded in** an outdoor surface, including pavement and CT process building slabs, that would cause no more than 25 mrem/yr. Results have been compared with dose modeling underlying basis Table 5-3 in CT 2 DP §5. Whether concentrating a source on a surface or assuming it is embedded into pavement or a building slab would produce maximum annual dose becomes a central question to be investigated. To do this,

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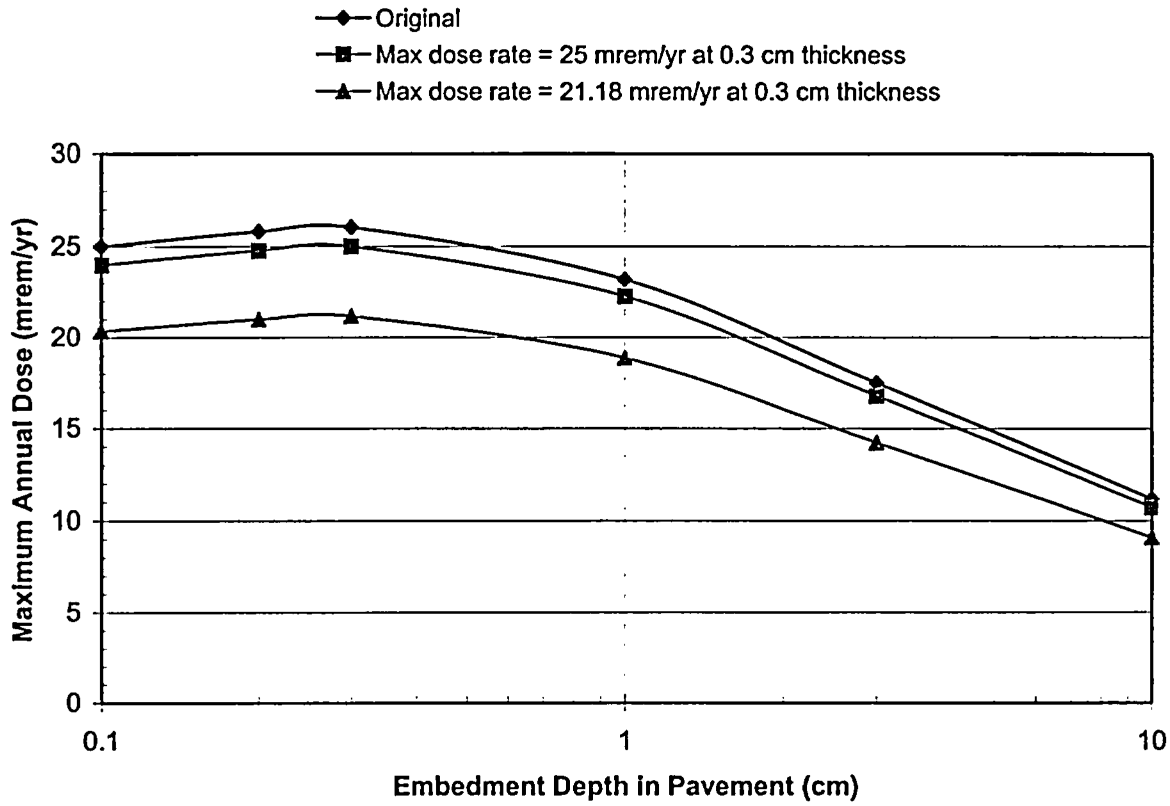
[44] Whereas, RESRAD-BUILD simulates indoor contamination with indoor dust suspension and ventilation models. Both are inappropriate for outdoor airborne exposure modeling.

- A reasonable spectrum of radionuclides in CT residue is represented by a ratio of 3 U series + 0.0455 x 3 U^{235} series + 1 Th series in radioactive equilibrium.
- The relative radioactivity fraction in this ratio and the basis dose factor[45] of each key radionuclide are used with a sum-of-fractions expression to derive the areal density and equivalent mass concentration in dust (soil at 1.5 pCi/g density) on pavement surface that would produce 25 mrem/yr.
- Enter this areal density equivalent mass concentration into RESRAD with the same parameter values otherwise used as a basis to derive the areal $DCGL_W$ in CT 2 DP §5, Table 5-3 to verify whether it calculates 25 mrem/yr maximum total dose rate.
- Assume the same radionuclide spectrum at the same areal density were embedded into pavement (represented by 1.5 g/cm^3 soil). Use RESRAD to compute maximum total dose rate as a function of increasing depth of embedment.

A premise of CT 2 DP, §5, Table 5-3 is that an equivalent areal density of CT residue would produce less dose when embedded than when accumulated on the surface; hence the source was originally modeled as concentrated into a 0.1 cm layer on the surface. Unexpectedly, maximum total dose occurs when the source is 0.2 to 0.3 cm thick, or deep, as illustrated in Figure 48, curve "♦ Original."

[45] The basis dose factor (mrem/yr)/(pCi/g) on which the areal $DCGL_W$ in CT 2 DP is derived.

Figure 48 Refinement of CT 2 DP §5 Model for Pavement



This observation prompted derivation of $DCGL_W$ assuming 0.3 cm contaminant thickness of the long-lived radionuclides in the uranium series, the actinium (U^{235}) series, and the thorium series, assuming short-lived nuclides (<180 day half-life) to be in transient radioactive equilibrium with their parent. The revised result appears here in Table 48-1. The result of this refinement is illustrated in Figure 48 by the curve, "■ Max. Dose Rate = 25 mrem/yr at 0.3 cm thickness". Thus, if contamination were on the surface or even if it were unevenly embedded into pavement or a building slab, controlling to a maximum areal density specified in Table 48-1 would assure that maximum annual dose would not exceed 25 mrem/yr.

Table 48-1. Uranium Series and Thorium Series Limits on Pavement Surface
Derivation Basis is 0.3 cm Thick Surficial Source

Radionuclide	Dose Factor (mrem/yr)/(pCi/g)	Areal Density Equal to 25 mrem/yr (pCi/100 sq cm)	Areal Density Equal to 25 mrem/yr (dpm/100 sq cm)
U-238	6.349E-04	1.77E+06	3.93E+06
U-235 +DI	2.018E-02	5.58E+04	1.24E+05
U-234	5.238E-05	2.15E+07	4.77E+07
Th-230	1.561E-04	7.21E+06	1.60E+07

Ra-226	4.825E-02	2.33E+04	5.18E+04
Pb-210	1.269E-03	8.87E+05	1.97E+06
Th-232	1.954E-03	5.76E+05	1.28E+06
Ra-228	1.911E-02	5.89E+04	1.31E+05
Th-228	3.421E-02	3.29E+04	7.30E+04
U-238 +DI	5.128E-02	2.19E+04	4.87E+04
Th-232 +DI	5.527E-02	2.04E+04	4.52E+04

Our response to NRC query expressed in item 4 herein concerning potential irradiation from hypothetical C-T residue in soil beneath pavement, states, in part:

> With the aid of dose modeling of outdoor exposure to gamma radiation penetrating nominal 4-inch-thick pavement by RESRAD, one finds that 2 meters of soil containing $DCGL_W$ concentration of 3 U-to-1 Th series source would be estimated to contribute 3.8 mrem/yr through the pavement. Subtracting that from 25 mrem/yr allotted to DCGL would imply reduction of conceivable contribution from residue on pavement itself to 0.85 of the $DCGL_W$ derived for pavement and would eliminate question of allocation of maximum acceptable total dose.

Although it is unlikely that both soil and pavement would be contaminated to more than 0.85 of either $DCGL_W$, and thus are practically independent, $DCGL_W$ on pavement in CT 2 DP §5, Table 5-3, is being reduced by 0.15 to values in Table 48-2 herein, which become the revised $DCGL_W$ to be applied. As a consequence, $DCGL_{EMC}$ will also be reduced to nominally 0.85 of currently proposed values.

Table 48-2. Uranium Series and Thorium Series Limits on Pavement Surface

Radionuclide	Dose Factor	**Areal Density Equal to 21.2 mrem/yr**	
	(mrem/yr)/(pCi/g)	(pCi/100 sq cm)	(dpm/100 sq cm)
U-238	6.349E-04	1.50E+06	3.33E+06
U-235 +DI	2.018E-02	4.72E+04	1.05E+05
U-234	5.238E-05	1.82E+07	4.04E+07
Th-230	1.561E-04	6.11E+06	1.36E+07
Ra-226	4.825E-02	1.98E+04	4.39E+04
Pb-210	1.269E-03	7.51E+05	1.67E+06
Th-232	1.954E-03	4.88E+05	1.08E+06
Ra-228	1.911E-02	4.99E+04	1.11E+05
Th-228	3.421E-02	2.79E+04	6.18E+04
U-238 +DI	5.128E-02	1.86E+04	4.13E+04
Th-232 +DI	5.527E-02	1.72E+04	3.83E+04

Figure 48, curve "▲ Max dose rate = 21.18 mrem/yr at 0.3 cm thickness," confirms that the revised $DCGL_W$ in Table 48-2, to become CT 2 DP §5, Table 5-4 (replacing Table 5-3),[46] would constrain maximum potential annual dose from contamination on pavement, even if embedded, to no more than 21.2 mrem/yr.

[46] Existing Table 5-2, the $DCGL_W$ for a construction scenario, is being omitted.

Erosion of Pavement. The reason for assuming no erosion of pavement was to simulate sustaining the surficial source in order to maximize potential dose. Whereas, apparent concern of agency staff about maintenance of pavement for 1000 years seems to imagine it to be needed to shield against gamma irradiation by residue in soil beneath. Consider, however,

- Gamma radiation from residual source in soil beneath pavement would, at its $DCGL_W$, contribute about 3.8 mrem/yr, or 0.15 of 25 mrem/yr, by irradiation through pavement.
- Weathering is likely to remove surficial residue from pavement, or if ever present, has already done so already.
- It is reasonable to expect surficial contamination on outdoor pavement to be removed by weathering more rapidly than erosion of pavement would allow gamma radiation penetrating from beneath it to increase.
- Even if a surficial source initially at its $DCGL_W$ were to migrate into pavement or a slab, it would diminish to the $DCGL_W$ appropriate for soil, specified in CT 2 DP §5, Table 5-1, within about 6 cm depth into the pavement or slab, such that the combined dose rate would be no greater than for soil alone, even as the pavement was eroding.

That the erosion rate of source sediment on pavement is assumed to be zero maintains the source in RESRAD simulation present on the pavement surface indefinitely in order to assess whether maximum dose might be greater in future than near the beginning time of simulation. Since the maximum dose occurs near the beginning time of simulation, the assumption of zero erosion rate of source from pavement surface is otherwise of no practical consequence to the $DCGL_W$ derived with the aid of RESRAD.

If the pavement were to erode, a surficial source would be expected to disappear more readily, or at least would disappear at the rate of erosion of the pavement. That is, as pavement erodes, dose from surficial source, even if embedded into pavement, would diminish more than dose from source in soil beneath would increase. In either prospect, the source inventory per unit area on or in pavement may be as much as allowed by Table 48-2 and the 25 mrem/yr dose criterion would still be satisfied. Another perspective is that **modeling a source on pavement as a thin, surficial source maximizes potential radiological dose per unit areal density.** If the source were embedded into pavement, ease of removal for contamination of worker hands or clothing and potential for ingestion would be diminished. Likewise, ease of removal from the surface to become suspended in air for potential inhalation would be diminished. Furthermore, unlike an embedded source, a surficial source is without shielding by its substrate.

49. (i) Area Factor for Elevated Measurements:

The licensee calculated the area factor for the industrial scenario elevated measurements exposure to soil and to pavement. The area factor is the ratio of the composite dose factor for the survey unit area to the composite dose factor for the local area (e.g., elevated measurements) of contamination. The licensee calculated the area factor for elevated measurements criterion in soil using contaminated areas of 10, 30, 100, 200, 1000, and 2000. A survey unit area of 10,000 m^2 was used for derivation of the area factor. In summary the area factor varied in the range of 1.1 (for an elevated area of 1000 m^2) to 2.3 for an elevated area of 10 m^2 for the composite radionuclide source of U-series , Ac-series, and Th-series. Similarly, the licensee calculated the area factors for elevated measurements on pavements for areas ranging from 10 m^2 to 2000m^2. These factors were found to vary in the range of 5.5 for the 10 m^2 area to 1.2 for the 2000m^2 area. The comments provided above regarding derivation of the $DCGL_w$ would also be applicable to derivation of the elevated measurements using the area factor (*e.g.*, the $DCGL_{EMC}$).

Response:

Area factors for elevated measurements with respect to contaminated soil and to pavement are presented in CT 2 DP, §5, revised Figures 5-3 and 5-4 respectively. Derivation of $DCGL_W$ for soil and $DCGL_W$ for pavement have been estimated probabilistically. Since $DCGL_W$ in the equation, $DCGL_{EMC}$ = Area factor x $DCGL_W$, were revised, the corresponding simulations as a function of diminishing area have also been revised.

Table 5-1 in CT 2 DP is being replaced by Table B4 in Appendix B, herewith, and its identification revised to Table 5-3. It becomes the basis for revised derivation of $DCGL_{EMC}$ to replace CT 2 DP Figure 5-1, "Area Factors for Elevated Measurements Criterion for Soil." Revised area factors appear hereafter in revised Figure 5-3

Table 5-3 in CT 2 DP is being replaced by Item 48, Table 48-2 herein and is being identified as Table 5-4 in CT 2 DP §5. Table 48-2 becomes the basis for revised derivation of $DCGL_{EMC}$ to replace CT 2 DP Figure 5-2, "Area Factors for Elevated Measurements Criterion for Pavement." Revised area factors appear hereafter in revised Figure 5-4.

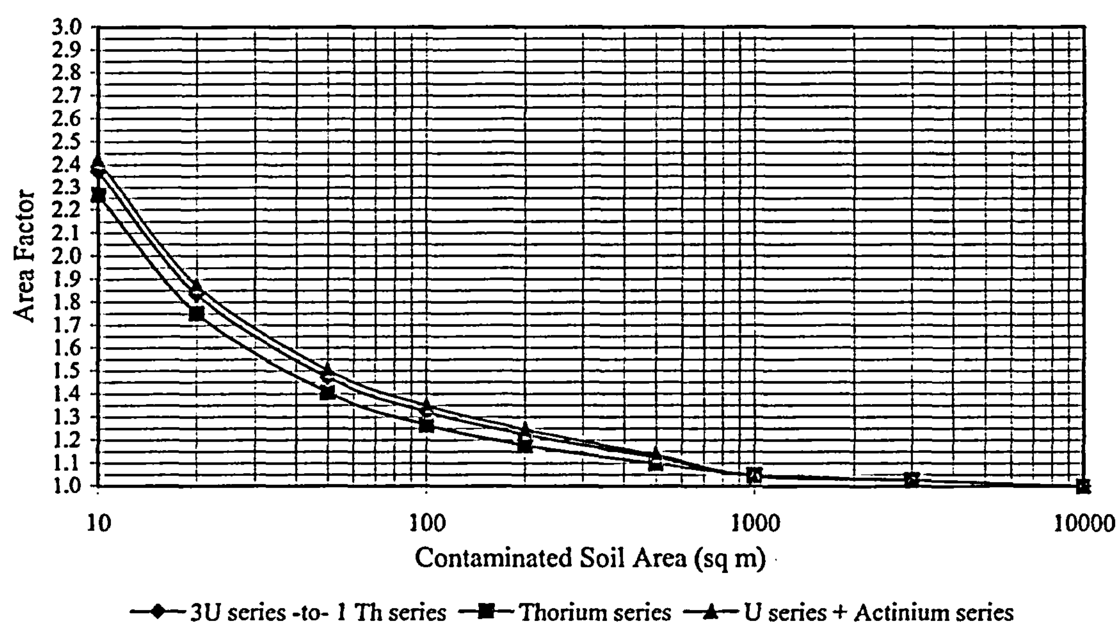


Figure 5-3. Area Factors for Elevated Measurements Criterion for Soil

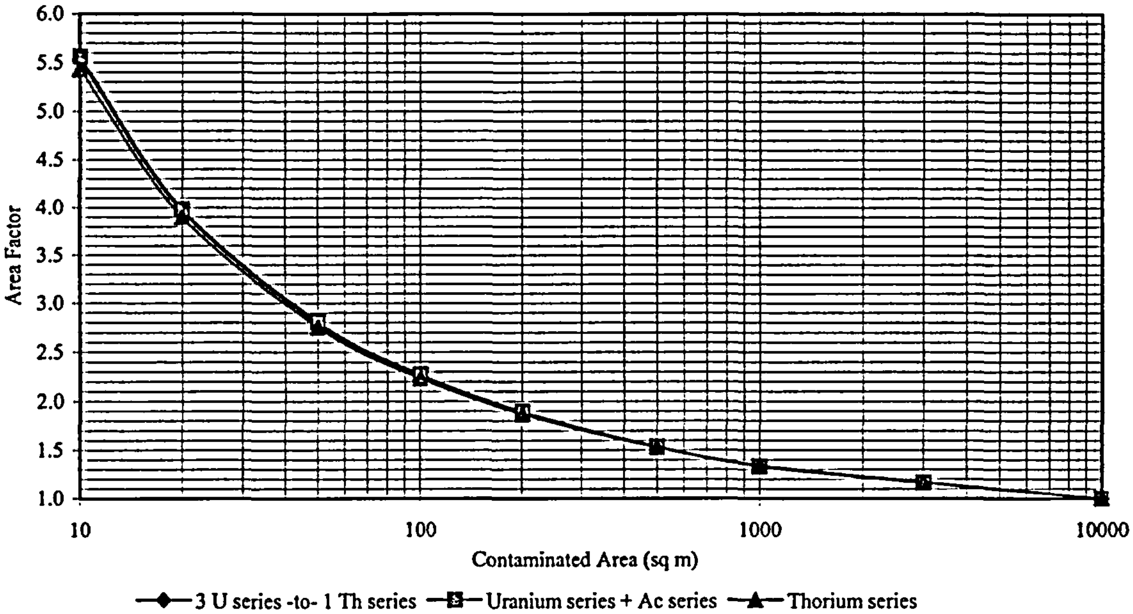


Figure 5-4. Area Factor for Elevated Measurements on Pavement

ADDENDUM TO RESPONSES

The staff requests information to clarify values of certain of the parameters in the modeling of residual radioactive source-to-radiological dose essential to derivation of the proposed DCGL.[47] They inquire about:

- residual radionuclide source as a function of depth in soil, *i.e.*, the *contaminated zone thickness*;
- density of respirable particulate in air, *i.e.*, the *mass loading for inhalation*;
- fraction of radiological dose experienced indoors as a result of gamma irradiation by residue in soil (relative to dose if the building occupied were assumed to provide no attenuation of radiation), *i.e.* the *external gamma shielding factor*;
- occupancy time indoors and, separately, out-of-doors, *i.e.*, *indoor time fraction* and *outdoor time fraction*.

Specific inquiries about these parameters are stated in the EPAD draft request for additional information, items a, b, c, and d (corresponding items 41, 42, 43, and 44 herein) and are addressed in responses thereto.

In common, these inquiries question whether description of these parameters as probabilistic distributions might be preferable to a best single-valued estimate of each. While each parameter was evaluated in response to items 41 through 44, residual radioactive source in

[47] Eid, Boby. "Draft RAIs, EPAD Staff Review of Dose Assessment for Mallinckrodt C-T Phase II Decommissioning Plan, Request for Additional Information. Nov. 29, 2004.

soil-to-radiological dose modeling has been revisited, incorporating findings described in items 41 through 44. The revised, probabilistic modeling is described in Appendix 4144, herewith. Table 4144B therein summarizes dose factors and $DCGL_W$ derived as a result of this revised dose modeling. Table 5-1 in CT 2 DP is being replaced by Table 4144B, to be identified as Table 5-3 in CT 2 DP §5. It also becomes the basis for derivation of $DCGL_{EMC}$ to replace CT 2 DP Figure 5-1, "Area Factors for Elevated Measurements Criterion for Soil," to be identified as Figure 5-3.

Appendix 30
Supplement to Response to NRC RAI Item 30

RAI Group 1
August 1, 2005

APPENDIX 30
TWO SMALL CONTAMINATED AREAS OF SOIL IN PLANT 5

Two small areas whose radioactive contamination causes their classification to differ from the larger areas surrounding them are identified in CT 2 DP, §14, Figure 14-2. One is southeast of Building 245; the other is east of Building 240. Since these are known small areas subject to alternate treatment in accordance with revised CT 2 DP, §14.4.3.9, and since the NRC staff asks notification and approval of such, John Buckley recommended that these two small areas be identified and justified in response to their queries about the draft CT 2 DP. These two small areas and related characterization survey data are described hereafter.

1.1. SOUTHEAST OF BUILDING 245

A small area of soil contamination has been identified near the southeast corner of Building 245,[1] within a Class 3 area of lesser contamination potential. Three shallow soil samples in one core sampling location, BH 43, contained residual source material as indicated in Table 30-1. The topsoil sample contained >$DCGL_W$, attributable to Ra^{226}. Localized, with radioactivity diminishing with depth, suggests a surficial contaminating event. When the local, elevated contamination is removed, the remaining small area will be Class 2[2] or perhaps even Class 3.

After clean-up, the vicinity of the small area would logically qualify as one in which the number of measurements estimated to satisfy a WRS test would be unreasonably large. Consistent with the framework for such contingency described in CT Phase II DP, §14.4.3.9 (previously §14.4.3.8), a final status survey should include at least one measurement per 25 m^2 in the small survey unit, and the release criterion shall be that no measurement may exceed the $DCGL_W$. All the surface of the small survey unit would be subject to a gamma scan as part of the final status survey.

1.2. EAST OF BUILDING 240

A small, Class 1 area[3] has been identified adjacent the east side of Building 240.[4] Five samples, in a line, including one of sediment taken from a sewer manhole, exhibited composite radioactivity concentration ≥ 0.5 $DCGL_W$. The samples containing the most source material were shallow, the deepest being 4.5 feet.

Of 35 soil or sediment samples taken in 15 locations in the vicinity (ref. Table 30-2 herein), 30 samples contained < 0.5 $DCGL_W$, suggesting that the contaminated area is

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1 CT Phase II Decommissioning Plan, §14 Facility Radiation Surveys, Figure 14-2.

2 Class 2 indicates an area is impacted by residual radioactivity, has low potential for containing residual radioactivity concentration > $DCGL_W$, and has little or no potential for a small area of radioactivity > $DCGL_{EMC}$.

3 Class 1 indicates reasonable expectation that soil in the unit may contain radioactivity concentration greater than the $DCGL_W$.

4 CT Phase II Decommissioning Plan, §14 Facility Radiation Surveys, Figure 14-2.

confined as CT 2 DP, §14, Figure 14-2 indicates. Since the contamination is apparently in a shallow, narrow zone, it might be justifiable to treat it as a discrete remediation and survey unit.

After clean-up, the vicinity of the small area would logically qualify as one in which the number of measurements estimated to satisfy a WRS test would be unreasonably large. Consistent with the framework for such contingency described in CT Phase II DP, §14.4.3.9 (previously §14.4.3.8), a final status survey should include at least one measurement per 25 m^2 in the small survey unit, and the release criterion shall be that no measurement may exceed the DCGLw. All the surface of the small survey unit would be subject to a gamma scan as part of the final status survey.

Table 30-1. Source Material Concentration in Soil Core Samples Near the Southeast of Building 245

Location I.D.	CT 2 DP Figure	CT 2 DP Table	Sample Depth Top (ft)	Sample Depth Bottom (ft)	Fraction of DCGLw	Radioactivity Concentration: Uranium (pCi/g)	Th^{230} (pCi/g)	Ra^{226} (pCi/g)	Thorium (pCi/g)
BH 34	4-7	4-7	3	4	0.2	5.6 [e]	6.3	6.9	1.3 [c]
BH 34	4-7	4-7	9	10	0.1	4.3 [e]	5.8	4.6	2.4 [c]
BH 34	4-7	4-7	15	16	0.0	2.5 [e]	2.1	1.3	1.4 [c]
BH 43	4-7	4-7	0.5	1	1.6	3.9 e	3.0	50.5	1.9 [c]
BH 43	4-7	4-7	2	3	0.8	10.2 a	-	24.8	1.8 [c]
BH 43	4-7	4-7	3	4	0.0	4.1 a	-	2.2	1.8 [c]
BH 43	4-7	4-7	4	5	0.3	4.3	2.9	11.8	1.3 [c]
BH 43	4-7	4-7	10	11	0.0	5.2	7.7	0.9	1.3 [c]
BH 120	4-8	4-8	8	9.	0.0	2.3 [e]	4.2	3.0	1.1 [c]
BH-Z-9	4-13	4-13	0	1	0.0	11.6 [e]	4.6	0.3	0.6 [c]
BH-Z-9	4-13	4-13	1	3	0.0	6.8 [e]	4.0	0.3	0.9 [c]
BH-Z-9	4-13	4-13	3	6	0.0	4.5 [e]	3.1	0.3	0.9 [c]
BH-Z-9	4-13	4-13	6	9	0.0	4.2 [e]	2.9	0.5	0.6 [c]
BH-Z-9	4-13	4-13	9	12	0.0	4.0 [e]	3.3	0.3	0.9 [c]
JA 21	4-16	4-16	3	4	0.1	3.9	3.3	4.0	1.2 [c]
JA 22	4-16	4-16	3	4	0.0	4.9	3.1	1.9	1.1 [c]
JA 23	4-16	4-16	3	4	0.0	2.7	2.4	2.3	1.3 [c]
JA 30	4-16	4-16	9	10	0.0	4.2	3.3	2.5	0.6 [c]

a U^{238}
b Th^{232}
c Average of Th^{232}, Ra^{228}, and Th^{228}
d Ra^{228}
e Average of U^{234} and U^{238}

Table 30-2. Source Material Concentration in Soil Core Samples Near the East Side of Building 240

Location I.D.	CT 2 DP Figure	CT 2 DP Table	Sample Depth Top (ft)	Sample Depth Bottom (ft)	Fraction of DCGLw	Uranium (pCi/g)	Th^{230} (pCi/g)	Ra^{226} (pCi/g)	Thorium (pCi/g)
JA 02	4-16	4-16	0	1.	0.5	90 [a]	60.7	13.4	2.2 [b]
JA 03	4-16	4-16	0	1,	1.0	28 [a]	41	28	3.1 [b]
JA 04	4-16	4-16	0	1.	4.8	33 [a]	80	133	8.2 [b]
JA 05	4-16	4-16	0	1.	0.2	27 [a]	50	4.8	2.0 [b]
JA 06	4-16	4-16	0	1.	8.3	36 [a]	54	243	5.9 [b]
JA 07	4-16	4-16	0	1.	0.2	52 [a]	61	2.5	2.5 [b]
JA 09	4-16	4-16	0	1.	0.1	70 [a]	50	2.7	1.9 [b]
JA 10	4-16	4-16	0	1.	0.2	71 [a]	81	2.6	2.3 [b]
BH 25	4-7	4-7	2.5	3.5	0.4	82	8.9	4.1	0.9
BH 25	4-7	4-7	4	5	0.1	65	-	2.3	0.6
BH 25	4-7	4-7	8	9	0.1	76	1.9	1.6	1.0
BH 26	4-7	4-7	2.5	3.5	0.4	8.2	-	13.7	1.1 [d]
BH 26	4-7	4-7	4	5	0.7	18.	25.	22.	0.6 [c]
BH 26	4-7	4-7	5	6	0.0	13.	-	1.3	2.6 [d]
BH 26	4-7	4-7	7	8	0.0	11.	-	< 0.6	2.5 [d]
BH 26	4-7	4-7	9	10	0.0	2.2	-	1.2	2.9 [d]
BH 26	4-7	4-7	12	13	0.2	8.0 [e]	6.8	8.5	1.1 [c]
BH 26	4-7	4-7	15	16	0.0	1.1	1.5	1.2	1.3 [c]
BH 83	4-15	4-15	0.5	1.5	0.0	23.9 [e]	24.4	2.0	0.6 [c]
BH 83	4-15	4-15	3.	4.5	0.2	98 [e]	8.4	2.7	1.6 [c]
BH 83	4-15	4-15	6	7.5	0.1	30.3 [e]	2.3	2.9	1.1 [c]
BH 83	4-15	4-15	10.5	12	0.0	1.4 [e]	0.9	1.5	0.9 [c]
BH 83	4-15	4-15	13.5	15	0.0	1.9 [e]	0.9	0.9	0.8 [c]
BH 83	4-15	4-15	16.5	18	0.0	0.8 [e]	1.2	1.0	1.1 [c]
BH 84	4-15	4-15	0.5	1.5	0.0	2.9 [e]	2.7	2.1	0.9 [c]
BH 84	4-15	4-15	3	4.5	0.0	2.5 [e]	2.3	1.1	0.9 [c]
BH 84	4-15	4-15	6	7.5	0.0	0.7 [e]	1.5	1.4	1.0 [c]
BH 85	4-15	4-15	1	1.5	0.0	2.0 [e]	1.4	1.5	0.7
BH 85	4-15	4-15	3	4.5	0.0	2.9 [e]	2.6	1.6	1.0
BH 85	4-15	4-15	6	7.5	0.0	0.6 [e]	0.6	0.5	0.6
BH 85	4-15	4-15	7.5	9	0.0	0.9 [e]	1.0	0.6	1.0
BH 111	4-11	4-11	0	2	0.0	7.7 [a]	1.9	0.8	1.1 [b]
BH 111	4-11	4-11	2	4	0.1	10.5	3.5	1.4	1.7 [b]
BH 111	4-11	4-11	4	6	0.0	3.1 [e]	0.8	0.4	0.9 [b]
MH 09 [f]	4-1	4-1	-	2.3	5.6		2.7	147	14.8 [c]

a U^{238}

b Th^{232}

c Average of Th^{232}, Ra^{228}, and Th^{228}

d Ra^{228}

e Average of U^{234} and U^{238}

f Sample MH 09 was sediment collected in a sewer manhole.

Appendix 45
Supplement to Response to NRC RAI Item 45

RAI Group 1
August 1, 2005

APPENDIX 45

DERIVATION OF DOSE FACTORS AND DCGLw APPLIED TO C-T PHASE II DECOMMISSIONING

1. THE OBJECTIVE

A vital criterion for decommissioning is that the radiological dose from all licensed radionuclides shall not exceed an appropriate dose limit in 10 CFR Part 20, Subpart E. Successful decommissioning may be demonstrated by either 1) entering radionuclide survey data into accepted modeling and calculating radiological dose or 2) deriving a concentration guideline level (DCGL) by acceptable modeling and comparing final status survey data and the DCGL.[1] When radionuclide concentrations are known by final status survey, a representative source description may be entered into the model and annual dose may be calculated during a range of future time. Alternatively, when DCGL are derived *a priori* to be a maximum acceptable radioactivity concentration as a remediation goal, their derivation must accommodate later comparison of final status survey data and DCGL of individual radionuclides to assess compliance.

2. THE ISSUE

The NRC staff has questioned whether a choice made by Mallinckrodt's technical consultant when deriving DCGL is conservative and consistent with NUREG-1757. The NRC staff stated that "This approach is no[n]-conservative and contrary to the recommendation of NRC Guidance in NUREG-1757, Vol. 2, Section 2.7." Specifically, the consultant derived the DCGLw for each radionuclide from the dose factor applicable at the time the maximum total dose was caused by the whole source term. Whereas, the NRC staff, citing NRC guidance,[2] suggests that DCGLw for each radionuclide be derived from the dose factor applicable at the time the maximum dose would occur from each radionuclide as if it were alone. The essence of the issue is whether, for the circumstance existing after Mallinckrodt C-T decommissioning, the method proposed by the technical consultant is or might be substantially non-conservative.

NRC guidance[3] recognizes that when separate radionuclides produce peak dose at separate times, a sum-of-fractions based on DCGLs derived independently of each other would overestimate the dose and fraction of the dose limit posed by their combination. Guidance documents also recognize that, in the presence of multiple radionuclides, the DCGLs need to be adjusted to account for the presence of the multiple radionuclides contributing to the total dose[4] or else the dose may be calculated on the basis of survey data.[5] If DCGLs are to be adjusted,

1 NRC. NUREG-1757. 2. §2.5.
2 NRC. NUREG-1757. 2. §2.7.
3 NRC. NUREG-1757, 2, §2.7.
4 MARSSIM, §4.3.3.
5 NRC. NUREG-1757, 2, §2.7.

guidance[6] states, "Due to the additive nature of the dose from each radionuclide, the total residual activity must be proportionally reduced to ensure the sum of each radionuclide divided by its DCGLw does not exceed one (unity)." This emphasizes the collection of radionuclides comprising the source and that, altogether, their sum-of-fractions is not to exceed one. Thus, when the source includes multiple radionuclides, the guidance does not require the impossibility of compositing doses into one year that actually occur in separate years.

3. BACKGROUND

3.1. MEANS OF RESOLUTION OF ISSUE

Since the DCGL approach is being taken, the issue may be resolved by calculating radiological dose for a relevant range of residual radionuclide sources in topsoil. Then one would examine whether the potential annual dose might be substantially underestimated by the DCGL proposed. The evaluation should account for and resolve the issue of whether the range of radionuclide sources would produce substantially different peak doses at different times. Corresponding dose factors[7] from which DCGL are derived are the convenient parameter for analysis.

3.2. C-T SOURCE

Historical assessment and characterization surveys have described the radionuclides of interest and their relative concentrations.[8] Radionuclides include the uranium series, the actinium series in naturally-occurring proportion to the uranium series, and the thorium series. The ratio of uranium in the U series -to- thorium in the Th series has been observed to be commonly in the range of 2 to 3 in the C-T residual source in Plant 5.

Relative proportions, or concentrations, of key radionuclides in the U series and in the Th series[9] have been estimated from characterization survey data that are above background.[10] The geometric mean ratios of each distribution of key radionuclides in those data are:

Th-230/U-238 = 1.1
Ra-226/U-238 = 2.8
Ra-228/Th-232 = 1.6
Th-228/Th-232 = 1.3
Th-228/Ra-228 = 0.8

Fifteen years after cessation of C-T processing is enough to allow thorium series nuclides to grow or decay within about 0.20 of radioactive equilibrium. Considering that

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6 NRC. NUREG-1757, 2, apx O, §O.3.4.2.
7 Dose factor = annual radiological dose (mrem/yr) per unit source per gram of soil (pCi/g)
8 Mallinckrodt C-T Phase II Decommissioning Plan. §4 Radiological Status of Facility.
9 Key radionuclides are those radionuclides, each of whose radioactive half-life is greater than 180 days and whose progeny down to the next radionuclide in the series whose radioactive half-life is also greater than 180 days are assumed in secular equilibrium with their parent key radionuclide.
10 Mallinckrodt. CT II DP. apx C.

CT feed was ore and that alpha spectrometry of separate radioelements poses uncertainty at low concentration, the thorium series might rationally be assumed to be in radioactive equilibrium in Plant 5 soil samples.

The data indicate Th^{230} is in approximate radioactive equilibrium with U^{238}. Ra^{226} tends to be in excess of parent U^{238} and Th^{230} by as much as a multiple of about 3 or sometimes more.

The characterization survey data suggest that a reasonable range of source terms to examine would be U -to- Th ratio of 2 to 3, with U series in radioactive equilibrium, with Th series, and with a range of excess Ra^{226}. The range of source terms examined is tabulated in Tables 1 and 11 herein.

Radionuclides in each natural decay series, *i.e.*, uranium series, actinium series (U^{235}), and thorium series, whose radioactive half-life was less than 180 days were assumed to be in secular equilibrium with their key parent radionuclide. Entering equal concentration of the key radionuclides in a decay series into RESRAD has the effect of posing the decay series in radioactive equilibrium. To simulate excess Ra^{226} in some cases, a larger concentration of Ra^{226} was entered than for the remainder of the U series.

3.3. Radiological Modeling

Argonne's RESRAD computer implementation of environmental exposure pathway -to- radiological dose models was employed to derive DCGL proposed in the CT Phase II Decommissioning Plan (CT 2 DP), §5. The same version, 6.1, in deterministic mode, and all of the same input data except the radionuclide source term was also used to perform the analysis reported herein. Industrial land use during the foreseeable future is the basis of modeling.

4. EVALUATION OF DOSE FACTORS

A way to examine whether $DCGL_W$ proposed in CT 2 DP §5, Table 5-1 are consonant with the 25 mrem/yr dose criterion is to scrutinize RESRAD calculations of underlying dose factors. A primary question is whether dose factors and DCGL derived therefrom are non-conservative or might be in future time.

4.1. Thorium Series

Dose factors of key, constituent radionuclides in the thorium series were derived and examined in a first step.

Receipt of ore, primary interest in extracting columbium and tantalum, time since processing, and characterization measurements support assumption that thorium series must be near radioactive equilibrium and may be assumed so. Equal, unit concentration of each of the 3 long-lived radionuclides in the thorium series, Th^{232}, Ra^{228}, and Th^{228}, were entered as the source in a RESRAD case, otherwise the same as modeled to derive dose factors and $DCGL_W$ in CT 2 DP §5, Table 5-1. Component and cumulative dose rates computed as a function of future time are in Figures 168C, 169A, 169B, 170A, and 170B.

Assuming radioactive equilibrium in the source term entered into RESRAD, dose factors of individually contributing key radionuclides were adopted at the time when RESRAD calculated maximum total radiological dose. For the thorium series and for the U series and Th series mixture, RESRAD computed that time to be in the first year of simulation.

If Th^{232} alone is entered into the RESRAD program, and its progeny having < 180 day half-life are assumed to be in radioactive equilibrium with it, growth toward thorium series radioactive equilibrium is governed by the 6.7 year half-life of Ra^{228} progeny. Component contributions, *i.e.*, each long-lived radionuclide plus its short-lived progeny in transient equilibrium, to dose rate are in Figure 169A. The consequent dose rate computed by RESRAD as function of future time may be seen in Figure 169B to reach its maximum about 50 years in the future.

If the first long-lived progeny of Th^{232}, *i.e.*, Ra^{228}, is entered into RESRAD in equal concentration with Th^{232}, Figure 170A shows that in early years it decays as its long-lived progeny, Th^{228}, and subsequent short-lived progeny grow, peak, and decay in effect. Together, Ra^{228} and its progeny contribute to total dose as shown in Figure 170B, enabling maximum dose to be reached about 10 years in the future, which has already been passed.

Then if the thorium series is simulated in radioactive equilibrium by entering equal concentrations of Th^{232}, Ra^{228} and Th^{228}, the maximum total dose rate occurs in the first year as may be seen in RESRAD graphical results in Figure 168C. Near immobility of Th^{232} and the thick source assumed, together sustain a practically unchanging dose rate.

By assuming the thorium series is in radioactive equilibrium initially, the maximum total dose rate is calculated to occur in the first year and will not be substantially greater in any future year. By measuring Th^{232} and or a surrogate to represent the thorium series, DCGL derived on the first year basis and judged by measurements assuming thorium series is in radioactive equilibrium will not substantially underestimate the annual radiological dose rate caused by the thorium series.

4.2. URANIUM SERIES

Inquiry into dose factors in the uranium series begins by entering U^{238} and U^{234} alone into the RESRAD program, and specifying their progeny whose half-lives are < 180 days are assumed to exist in radioactive equilibrium initially. These very long-lived uranium isotopes and progeny that grow from them eventually decline by migration into subsoil as indicated by diminishing dose rate in Figure 173B for U^{238} and its progeny and in Figure 173C for U^{234} and its progeny. Alone, isotopes U^{238} and U^{234} cause maximum dose rate in the first year after deposit in topsoil.

Assuming Th^{230} to be present initially in equal concentration with U^{238} and U^{234}, RESRAD simulation in Figure 172D shows that dose rate increases in time as Th^{230} progeny grow.

Entering equal concentration of Ra^{226} and Pb^{210} along with U^{238}, U^{234}, and Th^{230} into RESRAD simulates the uranium series in radioactive equilibrium. In addition to behavior of U^{238}, U^{234}, and Th^{230} described already, the effect of Ra^{226} progeny grows, governed by Pb^{210}, more than Ra^{226} declines, as is evident in Figure 171A and 171B. The Pb^{210}, assumed to be present initially, decays and thereby contributes diminishing dose rate, as is evident in Figure 171C.

Altogether, key radionuclides in the uranium series, assumed to be in radioactive equilibrium initially, contribute dose rate in future time as indicated in Figure 171D. When the uranium series is in radioactive equilibrium initially, total dose rate is seen to be practically constant during about 100 years and then decline. When the actinium (U^{235}) series in included in its naturally-occurring proportion with the uranium (U^{238}) series, total dose rate contributed by the uranium series is dominant; and dose rate from the combined series remains practically constant during about 100 years before declining. This is evident in Figure 167A.

By assuming the uranium series and actinium series are in radioactive equilibrium and in their naturally-occurring proportions initially, the maximum total dose rate is calculated to occur in the first year and will not be substantially greater in any future year. By measuring one or more uranium isotopes and or a surrogate to represent the uranium series, DCGL derived on the first year basis and judged by measurements assuming uranium series is in radioactive equilibrium will not substantially underestimate the annual radiological dose rate caused by the uranium series in the future.

4.3. Radium-226

Selection of dose factors representing radionuclides in the uranium, actinium, and thorium series in radioactive equilibrium at the time of maximum total radiological dose calculated by RESRAD modeling have been demonstrated not to be substantially non-conservative when taken together to calculate dose and to derive $DCGL_W$ for the range of residual source distribution expected to be observed in the final status survey. Characterization survey data indicate that Ra^{226} in soil in Plant 5 that is above the background concentration of uranium and thorium exists in higher concentration than the uranium. This suggests that after remediating soil to remove non-compliant residue, Ra^{226} can be expected to be present in excess of its equilibrium in the uranium series. Whether excess Ra^{226} and Pb^{210} might unseat the demonstration that dose factors at the time of maximum total dose and $DCGL_W$ derived therefrom are appropriate has also been examined in §4.4.

4.4. Combined Uranium Series and Thorium Series

Characterization survey data indicate final status surveys of soil affected by C-T operation will find a combination of uranium series, thorium series, and probably excess Ra^{226}. $DCGL_W$ derived from dose factors caused by the likely range of these residual radionuclides at the time of maximum total dose has been examined.

Annual radiological dose throughout 1000 years from present time was computed by RESRAD for industrial land use.

4.4.1. U Series + Th Series + Ra226 + Pb210

Source Distribution. A reasonably wide range of key uranium, thorium, and radium expected to be representative of the relative source distribution expected in final status survey is tabulated in Table 1. The contribution by each key, long-lived radionuclide (with short-lived progeny implicitly in secular equilibrium) and the sum of all as a function of future time is presented in these identified figures as computed by RESRAD.

In addition to the relative proportions of U series to Th series, a range of excess Ra^{226} and Pb^{210} was also evaluated. In these simulations, Pb^{210}, the long-lived ($\tau_{1/2}$ = 21 yr) progeny of Ra^{226}, was assumed to exist in secular equilibrium with the radium. Assuming Ra^{226} and Pb^{210} in equal concentration in excess effectively assumes Ra^{226} and all of its progeny are a decay subseries since the option to include progeny whose half-life is less than 180 days was invoked in RESRAD.

Table 1. Range of U Series, Th Series, Ra^{226}, and Pb^{210} Examined

Source	RESRAD case	Figure
1 U series + 1 Th series	19guti	19A
2 U series + 1 Th series	146guti	146A
2 U series + 1 Th series + 1 excess Ra^{226} + 1 excess Pb^{210}	156guti	156A
2 U series + 1 Th series + 2 excess Ra^{226} + 2 excess Pb^{210}	157guti	157A
2 U series + 1 Th series + 4 excess Ra^{226} + 4 excess Pb^{210}	158guti	158A
2 U series + 1 Th series + 6 excess Ra^{226} + 6 excess Pb^{210}	159guti	159A
2 U series + 1 Th series + 8 excess Ra^{226} + 8 excess Pb^{210}	160guti	160A
2 U series + 1 Th series + 10 excess Ra^{226} + 10 excess Pb^{210}	166guti	166A
3 U series + 1 Th series	147guti	147A
3 U series + 1 Th series + 2 excess Ra^{226} + 2 excess Pb^{210}	161guti	161A
3 U series + 1 Th series + 4 excess Ra^{226} + 4 excess Pb^{210}	162guti	162A
3 U series + 1 Th series + 6 excess Ra^{226} + 6 excess Pb^{210}	163guti	163A
3 U series + 1 Th series + 8 excess Ra^{226} + 8 excess Pb^{210}	164guti	164A
3 U series + 1 Th series + 12 excess Ra^{226} + 12 excess Pb^{210}	165guti	165A

Dose Factors. Figure 19A represents RESRAD case *19guti*, the basis of $DCGL_W$ in topsoil in CT 2 DP §5, Table 5-1. The relative source term for each RESRAD case in Figures 19A, 146 A, and 156A through 165A are identified in Table 1 herein. **RESRAD simulations indicate that maximum total dose rate from this range of relative**

source concentration in topsoil is expected to occur in the first year of exposure. Where Ra^{226} and Pb^{210} are in excess and are majority contributors of radiological dose, the figures show that adoption of their dose factors in the first year would not substantially underestimate future dose.

The dose factor for each radionuclide at the time of maximum total dose in each case in Table 1 entered into RESRAD is tabulated in Table 2. These long-lived radionuclides in each series are combined into a dose factor representing the series when in radioactive equilibrium. The combined dose factor for the U series, U +DI, includes both the uranium series and the actinium (U^{235}) series, assuming the actinium series is present in the naturally-occurring proportion in nature, 0.0455 pCi U^{235}/pCi U^{238}. The dose factor for each decay series is expressed relative to 1 pCi of the parent radionuclide in the series per gram of soil.

Whether the expected range of source conditions might produce higher dose and dose factors,[11] and consequent lower DCGLw at any future time than does the basis condition, case *19guti*, is in question. This may be evaluated by the following sequence:

- computing radiological dose computed across the range of source terms entered in this study in soil as a function of future time [ref. Table 1 herein]
- deriving dose factors per unit concentration for key radionuclides at the time of maximum total dose from the mixture [ref. Table 2]
- summing the dose factors into composites for the U series[12] and Th series [ref. Table 2];
- deriving DCGLw for each key, long-lived radionuclide and for the U series and Th series [ref. Table 7]
- applying those DCGLw to the radioactivity proportions in the mixture, *i.e.,* to the relative radioactivity concentration distribution of the radionuclides in the soil, to calculate maximum acceptable total radioactivity concentration of key radionuclides in the mixture in topsoil [ref. Table 8];
- deriving the concentration of each constituent, key radionuclide in soil when their mixture is at the DCGLw for the mixture [ref. Table 9]
- calculating the product of the concentration of each key constituent at its individual DCGLw and its corresponding dose factor and sum the contributing doses [ref. Table 10]

The nearness of the sum of these products to 25 mrem/yr for each mixture across the range of sources examined will be an indicator of the appropriateness of the time of maximum total dose as basis for deriving DCGLw for individual contributors.

For instance, the relative source entered into RESRAD for case *159guti* was 2 U series + 1 Th series + 6 Ra226 in excess of the 2 Ra^{226} in the U series in equilibrium; that included a total of 9 pCi key parent radionuclides/g soil initially. The maximum total dose computed at any future time in case *159 guti* was 8.36 mrem/yr [ref. Table 5]. Expressed per one pCi of key radionuclides in that distribution per gram soil, counting Pb^{210}, the dose would be 0.557 (mrem/yr)/(pCi/g) [ref. Table 6]. Normalized to 1 pCi of key radionuclides in a

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[11] Dose factor = annual radiological dose (mrem/yr) per unit source per gram of soil (pCi/g)

[12] Including actinium (U^{235}) series in naturally-occurring fraction with the U series.

mixture per gram soil, **results in Table 6 demonstrate that no mixture of radionuclides within the range expected would be estimated to cause more dose within 1000 years than estimated on the basis of dose factors tabulated in CT 2 DP §5, Table 5-1.**

An insight into influences on these results may be extracted by calculating the fraction of total dose caused by Ra^{226} + Pb^{210} and their progeny among all sources within the U +DI series, *i.e.* U^{238} series + 0.0455 U^{235} series.[13] In each case within the range of source mixtures examined, the dose factor for Ra^{226} + Pb^{210} + ingrown progeny as a fraction of the combined dose factor for the U series + 0.0455 U^{235} series in radioactive equilibrium was calculated. Results in Table 4 indicate that Ra^{226} + Pb^{210} and their progeny contribute 0.95 of the dose caused by U^{238} +DI, *i.e.*, when the U series is in radioactive equilibrium (without excess Ra^{226}).

The fraction of total dose caused by all sources in the mixture that is attributable to Ra^{226} + Pb^{210} and their progeny is presented in Table 4. Across the range of source distribution described in Table 1, that fraction ranges from 0.95 to 0.99. When Ra^{226} and Pb^{210} are in excess of the U series in equilibrium, more than 0.95 of dose is attributable to Ra^{226}, Pb^{210}, and their short-lived progeny.

Another insight interpreted from Figure 19A is that since the U series is assumed to be in radioactive equilibrium initially, decay of its progeny is practically balanced by growth from Ra^{226} itself within about the first 100 years. Total dose declines over longer time, most likely as uranium and radium migrate into subsoil. Examination of other Figures 146A through 165A reveal this near-balancing of effect of ingrowth of progeny from excess Ra^{226} and disappearance of Ra^{226} source from topsoil.

DCGLw. Whether DCGLw derived from dose factors interpreted at the time of maximum total dose caused by an expected range of source distributions would be non-conservative (unduly large) is in question. To examine this, DCGLw were derived for key, long-lived radionuclides and for their U series and Th series in radioactive equilibrium across a reasonably expected range of source distribution identified in Table 1. In this part of the examination, Ra^{226} and Pb^{210} were assumed to exist in equal concentration in excess of the U series. This part of the examination tests whether presence of excess Ra^{226} and its progeny in excess of equilibrium with the U series with it might cause DCGLw to be substantially higher than it should be and whether DCGLw in CT 2 DP §5 Table 5-1, derived from case *19guti*, might be substantially non-conservative.

Table 7 tabulates DCGLw by key, long-lived radionuclides and composited in DCGLw for the decay series. **None of the combinations of sources including excess Ra^{226} and Pb^{210} initially in excess of the U series yields DCGLw greater than proposed in CT 2 DP §5, Table 5-1, which were derived on the basis of RESRAD case *19guti*.**

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[13] Thorium series is not being considered in estimating this this fraction.

4.4.2. U Series + Th Series + Ra^{226}

Dose Factors. Another conceivable permutation could be to have less Pb^{210} than Ra^{226} while Ra^{226} is in excess of U series in soil. The boundary condition of this was examined by assuming presence of excess Ra^{226} and absence of excess Pb^{210} for the range of source mixtures in Table 11.

The contribution to annual dose rate by each key radionuclide and by their sum as a function of future time is presented in Figures 19A and 147A through 155A. Figure 19A represents RESRAD case *19guti*, the basis of $DCGL_W$ in topsoil in CT 2 DP §5, Table 5-1. The relative source term and year in which maximum total dose occurs for each RESRAD case in Figures 19A and 147A through 155A are identified in Table 12. These results indicate that maximum total dose is expected to occur either in the first year or between 40 and 50 years later when Pb^{210} grows in.

Table 11. Range of U Series, Th Series, and Ra^{226} Examined

Source	RESRAD case	Figure
1 U series + 1 Th series	19guti	19A
2 U series + 1 Th series	146guti	146A
2 U series + 1 Th series + 1 excess Ra^{226}	148guti	148A
2 U series + 1 Th series + 2 excess Ra^{226}	149guti	149A
2 U series + 1 Th series + 4 excess Ra^{226}	150guti	150A
2 U series + 1 Th series + 6 excess Ra^{226}	151guti	151A
3 U series + 1 Th series	147guti	147A
3 U series + 1 Th series + 2 excess Ra^{226}	152guti	152A
3 U series + 1 Th series + 4 excess Ra^{226}	153guti	153A
3 U series + 1 Th series + 6 excess Ra^{226}	154guti	154A
3 U series + 1 Th series + 8 excess Ra^{226}	155guti	155A

The dose factor at the time of maximum total dose for each radionuclide in each case entered into RESRAD is tabulated in Table 12. These long-lived radionuclides in each series are combined into a dose factor representing the series when it is in radioactive equilibrium. The combined dose factor for the U series, U +DI, includes both the uranium series and the actinium (U^{235}) series, assuming the actinium series is present in the naturally-occurring proportion in nature, 0.0455 pCi U^{235}/pCi U^{238}.

Whether the expected range of source conditions might produce higher dose, and thus dose factors,[14] at any future time than does the basis condition, case *19guti*, is in question. This may be evaluated by expressing radiological dose computed across the range of source terms entered in this study per unit concentration in soil. For instance, the relative source entered into RESRAD for case *151guti* was 2 U series + 1 Th series + 6 Ra226 in excess of the 2 Ra^{226} in the U series in equilibrium; that included 9 pCi key radionuclides/g soil initially. The maximum total dose computed at any future time in case *151guti* was 8.14 mrem/yr [ref. Table 15]. Expressed per one pCi of key radionuclides in that distribution per gram soil, the dose would be 0.904 (mrem/yr)/(pCi/g) [ref. Table 16].

Normalized to a total of one pCi of key radionuclides in a mixture per gram soil, results in Table 16 demonstrate that no mixture of radionuclides within the range expected would be estimated to cause more dose within 1000 years than case *19guti*, which is the basis of dose factors tabulated in CT 2 DP §5, Table 5-1.

An insight into the behaviors influencing these results may be extracted by calculating the fraction of total dose caused by Ra^{226} and its progeny within the U +DI series, *i.e.* U^{238} series + 0.0455 U^{235} series. In each case within the range of source mixtures examined, the dose factor for Ra^{226} + ingrown progeny as a fraction of the combined dose factor for the U series + 0.0455 U235 series in radioactive equilibrium was calculated. Results in Table 14 indicate that Ra^{226} and its progeny contribute 0.89 to 0.92 of the dose caused by U +DI when the U series is in radioactive equilibrium.

Another insight interpreted from Figures 19A and 146A through 155A is that since the U series is assumed to be in radioactive equilibrium initially, decay of its progeny is practically balanced by growth from Ra^{226} itself within about the first 100 years. Overall dose declines over longer time, most likely as uranium and radium migrate into subsoil. Examination of other Figures 156A through165A also reveal this near-balancing of effect of ingrowth of progeny from excess Ra^{226} and disappearance of Ra^{226} source from topsoil.

<u>DCGLw</u>. Whether DCGLw derived from dose factors interpreted at the time of maximum total dose caused by an expected range of source distributions would be non-conservative is in question. To examine this issue, DCGLw were derived for key, long-lived radionuclides and for their U series and Th series in radioactive equilibrium across a reasonably expected range of source distribution identified in Table 11. In this part of the examination, Pb^{210} was assumed to exist in equilibrium within the U series but was not initially present with excess Ra^{226}. This part of the examination tests whether growth of Pb^{210} from excess Ra^{226} might cause DCGLw to be substantially higher than it should be and whether DCGLw in CT 2 DP §5 Table 5-1, derived from case *19guti*, might be substantially non-conservative.

Table 17 tabulates DCGLw by key, long-lived radionuclides and composited in DCGLw for each decay series. None of the combinations of sources, including excess Ra^{226} without

[14] Dose factor = annual radiological dose (mrem/yr) per unit source per gram of soil (pCi/g)

Pb^{210} initially in excess, yield DCGLw substantially more restrictive than proposed in CT 2 DP §5, Table 5-1, which was derived on the basis of RESRAD case *19guti.*

5. DCGLw DERIVATION

Eventually, in this evaluation, DCGLw in Tables 7 and 17 were derived from dose factors in Tables 2 and 12 respectively for each case examined. Radionuclides in each natural decay series, *i.e.*, uranium series, actinium series (U^{235}), and thorium series, including nuclides whose radioactive half-life was less than 180 days, were assumed to be in secular equilibrium with their key, long-lived radionuclide parent. Thus, entering equal concentration of the key radionuclides in a decay series into RESRAD has the effect of posing the decay series to be in radioactive equilibrium. To simulate excess Ra^{226}, a larger concentration of Ra^{226} was entered than for the remainder of the U series. Neither excess Ra^{226} alone nor both Ra^{226} and Pb^{210} together in excess, caused DCGLw to be substantially lower in these deterministic analyses than proposed in CT 2 DP §5 Table 5-1 to apply in topsoil.

For the range of radionuclide mixtures in Tables 1 and 11, the maximum acceptable concentration of each key constituent in each mixture in Tables 9 and 19, when added together produce the maximum acceptable concentration in the composite mixture, or composite DCGLw, in Tables 8 and 18 respectively. No composite DCGLw was smaller than that from RESRAD case *19guti* on which CT 2 DP §5, Table 5-1 is based.

A way to test whether the logic of this exercise is reasonable would be to take the results and compute dose with RESRAD. If the maximum total dose computed by the same models in RESRAD is 25 mrem/yr, the method of deriving DCGLw within the source range expected will be confirmed to be acceptable. To do so, one would enter a source term comprised of the key constituents of a case in either Table 9 or 19 into RESRAD and have it compute the total radiological dose rate as a function of future time. If the logic is sound, the maximum total dose rate computed by RESRAD should not exceed 25 mrem/yr in any future year.

As test cases, DCGLw in Table 7 for U series, Th series, Ra^{226}, and Pb^{210} at the relative concentration distribution for RESRAD cases *147guti, 159guti,* and *164guti* [ref. Table 1] were entered into the sum-of-fractions equation to derive the DCGLw for the key radionuclides, *i.e.* parent of each series or subseries, in total. The product of the relative fraction of each of the key parent radionuclides and the total DCGLw derive the concentration of each key nuclide that, together, should cause 25 mrem/yr when computed by the same RESRAD models. When each of these source terms was entered into RESRAD, it computed 25 mrem/yr as the maximum total dose in any future year. The graphical results in Figures 174C, 176C, and 177C confirm the dose rate estimates. **These calculations demonstrate that applying DCGLw derived on the basis of maximum total dose rate would not allow non-conservative residual concentration in topsoil for the range of radionuclide mixtures reasonably expected in C-T decommissioning.**

NRC staff expressed concern with the method proposed to select dose factors and DCGL for radionuclides in the uranium, thorium, and actinium series encountered in CT decommission by commenting,[15]

> The licensee presented the DCGLw for each specific radionuclide (Table 5-1, page 5-3) based on the guidelines (e.g., radionuclide concentration equivalent to 25 mrem/yr) at the time of the peak dose ($G(i, t_{peak})$) of the overall radionuclides in the three decay series. This approach is no-conservative and contrary to the recommendation of NRC Guidance in NUREG-1757, Vol. 2, Section 2.7.

Apparently the NRC staff is concerned whether selection of dose factors for radionuclides applicable at the time the mixture demonstrates maximum total dose would be non-conservative for derivation of DCGLw. The apparent source of concern expressed in NUREG-1757. 2. §2.7 and repeated in §2 herein is demonstrated by this appendix to be unfounded with respect to the derivation of DCGLw and application intended in the C-T Phase II Decommissioning Plan. Circumstances and radiochemicals consequent to C-T processing do not present such disparate or dissociated uncertainty, largely owing to few, relatively direct exposure pathways and to nearness of the decay series to radioactive equilibrium.

Having extensive characterization survey data, calculating potential radiological dose for that relevant range of residual radionuclide sources in soil determines the maximum total dose and a corresponding set of DCGL. Adopting that set of DCGL will provide reasonable assurance that total dose from any spectrum of radionuclides to be encountered after remediation will not exceed the 25 mrem/yr criterion during any future year when controlled by using those DCGL in the unity rule. Since none of the combinations of sources [ref. Tables 1 and 11] enveloping those observed during extensive characterization survey yields DCGLw greater than proposed in CT 2 DP §5, Table 5-1, those proposed DCGLw, applied in sum-of-fractions for the uranium series and thorium series present, reasonably assure the 25 mrem/yr criterion will be satisfied.

6. MEASUREMENT

Decommissioning criteria must be reasonable to implement. The criteria and measurements to assess compliance must be mutually interpretable and compatible. Properties of the residual radioactive source observed during characterization surveys have enabled the radioactive properties and range of the source term expected to remain after remediation to be estimated. On that knowledge, the DCGLw were derived; the basis has been demonstrated to be valid; and compatible final status survey measurements to assess compliance can be made.

The thorium series will be assumed to be in radioactive equilibrium. One or more surrogate radionuclides such as Ac^{228} and or Tl^{208} may be measured as surrogate(s) to represent the concentration of key radionuclides and thus the thorium series.

[15] NRC Staff. "Draft RAIs EPAD Staff Review of Dose Assessment for MallinckrodtC-T Phase II Decommissioning Plan Request for Additional Information." item 4(e). Nov. 29, 2004.

Radium-226 may be measured, either directly and or by surrogate progeny to represent Ra^{226}. By measuring radium, the amount of its concentration in excess of its presence in the uranium series in radioactive equilibrium may be estimated.

Considering characterization survey data, the uranium series will be assumed to be in radioactive equilibrium together with the actinium (U^{235}) series in its naturally-occurring ratio. Either uranium isotope(s) may be measured during final status survey or surrogate progeny may be measured to represent the parent uranium.

7. EFFECT OF DERIVING DOSE FACTOR INDEPENDENTLY AT THE TIME OF MAXIMUM DOSE FROM AN INDIVIDUAL RADIONUCLIDE

With respect to employment of the sum-of-fractions of DCGL for radionuclides in a mixture to derive the maximum acceptable concentration or to test final status survey measurements, NRC guidance states,[16] "One major assumption that is necessary to accept in using the sum of fractions approach is the simultaneous occurrence of the peak dose for each radionuclide and source." The implication of NRC staff concern seems to be that the dose factor corresponding to the peak dose rate of each radionuclide independently of others that are also present should be the basis of DCGL. To adhere to this concept, one would have to derive the dose factor of each radionuclide independently of others in a mixture.

The consequence of that may be realized by the example of:

1. entering unit concentration of each of Th^{232}, Ra^{228}, and Th^{228}, independently, into the same industrial land use simulation that is the basis of $DCGL_W$ proposed in CT 2 DP §5, Table 5-1;
2. reading the dose factors at the time of maximum dose rate caused individually and separately by Th^{232}, Ra^{228}, and Th^{228};
3. summing the dose factors:

Parent Radionuclide	Time at Maximum Dose Rate (yr)	Maximum Dose Rate (mrem/yr)/(pCi/g)
Th^{232}	91.	1.204
Ra^{228}	2.7	0.7066
Th^{228}	0.0	0.6257
	Sum =	2.5363

4. and then separately, reading the maximum total dose rate at any future time computed by RESRAD by the same Th^{232}, Ra^{228}, and Th^{228} together and comparing with the sum, 2.5 mrem/yr per pCi/g.

As illustrated in Figure 168C, the maximum total dose rate caused by the mixture at any future time would be 1.222 (mrem/yr)/(pCi/g), occurring in the first year.

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[16] NRC. NUREG-1757. 2. §2.7

Since residual thorium series in soil remaining from C-T operation must be in approximate radioactive equilbrium, the maximum total dose at any future time would be represented by 1.2 mrem/yr per pCi parent Th^{232} per gram soil. The sum, 2.536 mrem/yr, of dose factors derived independently and occurring at different times would be more than 2 times the maximum total dose at any time computed by RESRAD. Thus, a convention of deriving DCGLw by combining dose factors from individual radionuclides, each causing maximum dose independently of others, and using sum-of-fractions of dose limit to combine them would produce a composite DCGLw that is unnecessarily restrictive by a factor of two in this application for the thorium series alone. Whereas, a composite DCGLw derived from dose factors effective at the time of maximum total dose produces the intended result in this application.

Table 2. Dose Factor DSR tmax for a Range of Radionuclide Mixtures (mrem/yr)/(pCi/g)

Parameter	Case												
	19guti	146guti	156guti	157guti	158guti	159guti	160guti	147guti	161guti	162guti	163guti	164guti	165guti
U series	1	2	2	2	2	2	2	3	3	3	3	3	3
Th series	1	1	1	1	1	1	1	1	1	1	1	1	1
excess Ra226	0	0	1	2	4	6	8	0	2	4	6	8	12
excess Pb210	0	0	1	2	4	6	8	0	2	4	6	8	12
Tmax (year)		0	0	0	0	0	0	0	0	0	0	0	0

Case = RESRAD case identification code
U series = relative concentration of U series in radioactive equilibrium, i.e., U238+DI + 0.0455 U238+DI, in soil entered in RESRAD source .
Th series = relative concentration of Th series in radioactive equilibrium, ii.e., Th232+DI in soil entered into RESRAD source
Excess Ra226 = relative concentration of Ra226 in excess of that in U series in soil entered into RESRAD source.
Tmax = time (year) at which maximum total radiological dose occurs after and as a result of radioactive mixture entered into RESRAD at time = 0 year

Radionuclide	Dose Factor DSR tmax (mrem/yr)/(pCi/g)												
Ac227	3.054E-01	3.054E-01	3.054E-01	3.054E-01	3.054E-01	3.054E-01	3.054E-01	3.054E-01	3.054E-01	3.054E-01	3.054E-01	3.054E-01	3.054E-01
Pa231	1.149E-01	1.149E-01	1.149E-01	1.149E-01	1.149E-01	1.149E-01	1.149E-01	1.149E-01	1.149E-01	1.149E-01	1.149E-01	1.149E-01	1.149E-01
Pb210	6.019E-02	6.019E-02	6.019E-02	6.019E-02	6.019E-02	6.019E-02	6.019E-02	6.019E-02	6.019E-02	6.019E-02	6.019E-02	6.019E-02	6.019E-02
Ra226	8.204E-01	8.204E-01	8.204E-01	8.204E-01	8.204E-01	8.204E-01	8.204E-01	8.204E-01	8.204E-01	8.204E-01	8.204E-01	8.204E-01	8.204E-01
Ra228	5.328E-01	5.328E-01	5.328E-01	5.328E-01	5.328E-01	5.328E-01	5.328E-01	5.328E-01	5.328E-01	5.328E-01	5.328E-01	5.328E-01	5.328E-01
Th228	6.257E-01	6.257E-01	6.257E-01	6.257E-01	6.257E-01	6.257E-01	6.257E-01	6.257E-01	6.257E-01	6.257E-01	6.257E-01	6.257E-01	6.257E-01
Th230	6.826E-03	6.826E-03	6.826E-03	6.826E-03	6.826E-03	6.826E-03	6.826E-03	6.826E-03	6.826E-03	6.826E-03	6.826E-03	6.826E-03	6.826E-03
Th232	6.331E-02	6.331E-02	6.331E-02	6.331E-02	6.331E-02	6.331E-02	6.331E-02	6.331E-02	6.331E-02	6.331E-02	6.331E-02	6.331E-02	6.331E-02
U234	3.193E-03	3.193E-03	3.193E-03	3.193E-03	3.193E-03	3.193E-03	3.193E-03	3.193E-03	3.193E-03	3.193E-03	3.193E-03	3.193E-03	3.193E-03
U235	5.819E-02	5.819E-02	5.819E-02	5.819E-02	5.819E-02	5.819E-02	5.819E-02	5.819E-02	5.819E-02	5.819E-02	5.819E-02	5.819E-02	5.819E-02
U238	1.286E-02	1.286E-02	1.286E-02	1.286E-02	1.286E-02	1.286E-02	1.286E-02	1.286E-02	1.286E-02	1.286E-02	1.286E-02	1.286E-02	1.286E-02
U235 +DI	4.785E-01	4.785E-01	4.785E-01	4.785E-01	4.785E-01	4.785E-01	4.785E-01	4.785E-01	4.785E-01	4.785E-01	4.785E-01	4.785E-01	4.785E-01
U238 +DI	9.252E-01	9.252E-01	9.252E-01	9.252E-01	9.252E-01	9.252E-01	9.252E-01	9.252E-01	9.252E-01	9.252E-01	9.252E-01	9.252E-01	9.252E-01
Th232 +DI	1.222E+00	1.222E+00	1.222E+00	1.222E+00	1.222E+00	1.222E+00	1.222E+00	1.222E+00	1.222E+00	1.222E+00	1.222E+00	1.222E+00	1.222E+00

Dose Factor DSR tmax = annual radiological dose contributed per unit radioactivity of individual radionuclide + progeny grown in since introduction at time = 0 year (mrem/yr/(pCi/g)
U235 +DI = DSR referenced to unit radioactivity of parent U235 when the actinium series is in radioactive equilibrium.
U238 +DI = DSR referenced to unit radioactivity of parent U238 when the uranium series and actinium series are present in radioactive equilibrium and U235 activity is 0.0455 of U238 activity.
Th232 +DI = DSR referenced to unit radioactivity of parent Th232 when the thorium series is in radioactive equilibrium.

Table 3. Ratio of Dose Factor for Series in Case ID -to- Dose Factor for Series in Case 19guti when Each Series is in Radioactive Equilibrium

	19guti	146guti	156guti	157guti	158guti	159guti	160guti	147guti	161guti	162guti	163guti	164guti	165guti
Ratio U235 +DI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ratio U238 +DI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ratio Th232 +DI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ratio Ra226	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ratio Pb210	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Ratio U235 +DI = ratio of dose factor for U235 series in identified case -to- dose factor in U235 series in case 19guti when each series is initially in radioactive equilibrium.
Ratio U238 +DI = ratio of dose factor for U238 series + U235 serie
Ratio Th232 +DI = ratio of dose factor for Th232 series in identified case -to- dose factor in Th232 series in case 19guti when each series is initially in radioactive equilibrium
Ratio Ra226 = ratio of dose factor for Ra226 + ingrown progeny in identified case -to- dose factor in Ra226 + progeny <180 days half-life in case 19guti

Table 4. Fraction of Total Dose Factor in U series and Excess Ra226 and Pb210 That Is Attributable to Ra226 + Pb210

	19guti	146guti	156guti	157guti	158guti	159guti	160guti	147guti	161guti	162guti	163guti	164guti	165guti
Ra226 + Pb210 /U238+DI	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Ra226 + Pb210 /All	0.95	0.95	0.97	0.98	0.98	0.99	0.99	0.95	0.97	0.98	0.98	0.99	0.99

Table 5. Dose Caused by Sum of Key Radionuclides in Mixture (mrem/yr)

	19guti	146guti	156guti	157guti	158guti	159guti	160guti	147guti	161guti	162guti	163guti	164guti	165guti
1U + 1Th	2.15												
2U + 1Th		3.07											
2U+1Th+1Ra+1Pb			3.95										
2U+1Th+2Ra+2Pb				4.83									
2U+1Th+4Ra+4Pb					6.59								
2U+1Th+6Ra+6Pb						8.36							
2U+1Th+8Ra+8Pb							10.12						
3U+1Th								4.00					
3U+1Th+2Ra+2Pb									5.76				
3U+1Th+4Ra+4Pb										7.52			
3U+1Th+6Ra+6Pb											9.28		
3U+1Th+8Ra+8Pb												11.04	
3U+1Th+12Ra+12Pb													14.56

2U+1Th+1Ra = 2 U series (incl U235 series in Unat) + 1 Th series + 1 Ra in excess of U series rad equilibrium.

Table 6. Dose Caused per Unit Radioactivity of Key Radionuclides in Mixture (mrem/yr)/(pCi/g)

	19guti	146guti	156guti	157guti	158guti	159guti	160guti	147guti	161guti	162guti	163guti	164guti	165guti
1U + 1Th	1.07												
2U + 1Th		1.02											
2U+1Th+1Ra+1Pb			0.79										
2U+1Th+2Ra+2Pb				0.69									
2U+1Th+4Ra+4Pb					0.60								
2U+1Th+6Ra+6Pb						0.56							
2U+1Th+8Ra+8Pb							0.53						
3U+1Th								1.00					
3U+1Th+2Ra+2Pb									0.72				
3U+1Th+4Ra+4Pb										0.63			
3U+1Th++6Ra+6Pb											0.58		
3U+1Th+8Ra+8Pb												0.55	
3U+1Th+12Ra+12Pb													0.52

2U+1Th+1Ra+Pb = 2 U series (incl U235 series in Unat) + 1 Th series + 1 Ra226 + 1 Pb210 in excess of U series rad equilibrium.

Table 7. DCGLw Derived at Time of Maximum Total Dose from Mixture

Case	19guti	146guti	156guti	157guti	158guti	159guti	160guti	147guti	161guti	162guti	163guti	164guti	165guti
U series	1	2	2	2	2	2	2	3	3	3	3	3	3
Th series	1	1	1	1	1	1	1	1	1	1	1	1	1
excess Ra226	0	0	1	2	4	6	8	0	2	4	6	8	12
excess Pb210	0	0	1	2	4	6	8	0	2	4	6	8	12
Tmax (year)	0	0	0	0	0	0	0	0	0	0	0	0	0
Radionuclide	DCGLw (pCi/g)												
Ac227	8.186E+01	8.186E+01	8.186E+01	8.186E+01	8.186E+01	8.186E+01	8.186E+01	8.186E+01	8.186E+01	8.186E+01	8.186E+01	8.186E+01	8.186E+01
Pa231	2.176E+02	2.176E+02	2.176E+02	2.176E+02	2.176E+02	2.176E+02	2.176E+02	2.176E+02	2.176E+02	2.176E+02	2.176E+02	2.176E+02	2.176E+02
Pb210	4.154E+02	4.154E+02	4.154E+02	4.154E+02	4.154E+02	4.154E+02	4.154E+02	4.154E+02	4.154E+02	4.154E+02	4.154E+02	4.154E+02	4.154E+02
Ra226	3.047E+01	3.047E+01	3.047E+01	3.047E+01	3.047E+01	3.047E+01	3.047E+01	3.047E+01	3.047E+01	3.047E+01	3.047E+01	3.047E+01	3.047E+01
Ra228	4.692E+01	4.692E+01	4.692E+01	4.692E+01	4.692E+01	4.692E+01	4.692E+01	4.692E+01	4.692E+01	4.692E+01	4.692E+01	4.692E+01	4.692E+01
Th228	3.996E+01	3.996E+01	3.996E+01	3.996E+01	3.996E+01	3.996E+01	3.996E+01	3.996E+01	3.996E+01	3.996E+01	3.996E+01	3.996E+01	3.996E+01
Th230	3.662E+03	3.662E+03	3.662E+03	3.662E+03	3.662E+03	3.662E+03	3.662E+03	3.662E+03	3.662E+03	3.662E+03	3.662E+03	3.662E+03	3.662E+03
Th232	3.949E+02	3.949E+02	3.949E+02	3.949E+02	3.949E+02	3.949E+02	3.949E+02	3.949E+02	3.949E+02	3.949E+02	3.949E+02	3.949E+02	3.949E+02
U234	7.830E+03	7.830E+03	7.830E+03	7.830E+03	7.830E+03	7.830E+03	7.830E+03	7.830E+03	7.830E+03	7.830E+03	7.830E+03	7.830E+03	7.830E+03
U235	4.296E+02	4.296E+02	4.296E+02	4.296E+02	4.296E+02	4.296E+02	4.296E+02	4.296E+02	4.296E+02	4.296E+02	4.296E+02	4.296E+02	4.296E+02
U238	1.944E+03	1.944E+03	1.944E+03	1.944E+03	1.944E+03	1.944E+03	1.944E+03	1.944E+03	1.944E+03	1.944E+03	1.944E+03	1.944E+03	1.944E+03
U235 +DI	5.225E+01	5.225E+01	5.225E+01	5.225E+01	5.225E+01	5.225E+01	5.225E+01	5.225E+01	5.225E+01	5.225E+01	5.225E+01	5.225E+01	5.225E+01
U238 +DI	2.702E+01	2.702E+01	2.702E+01	2.702E+01	2.702E+01	2.702E+01	2.702E+01	2.702E+01	2.702E+01	2.702E+01	2.702E+01	2.702E+01	2.702E+01
Th232 +DI	2.046E+01	2.046E+01	2.046E+01	2.046E+01	2.046E+01	2.046E+01	2.046E+01	2.046E+01	2.046E+01	2.046E+01	2.046E+01	2.046E+01	2.046E+01

Table 8. DCGLw of Combined Mixture of U Series + Th Series + Ra226 and Pb210 in Excess of U Series

case:	19guti	146guti	156guti	157guti	158guti	159guti	160guti	147guti	161guti	162guti	163guti	164guti	165guti
Mixture	DCGLw of Combined Mixture (pCi total/g)												
1U + 1Th	23.3												
2U+1Th		24.4											
2U+1Th+1Ra+1Pb			31.6										
2U+1Th+2Ra+2Pb				36.2									
2U+1Th+4Ra+4Pb					41.7								
2U+1Th+6Ra+6Pb						44.9							
2U+1Th+8Ra+8Pb							47.0						
3U+1Th								25.0					
3U+1Th+2Ra+2Pb									34.7				
3U+1Th+4Ra+4Pb										39.9			
3U+1Th+6Ra+6Pb											43.1		
3U+1Th+8Ra+8Pb												45.3	
3U+1Th+12Ra+12Pb													48.1

Table 9. Concentration of Each Constituent Radionuclide Series in DCGLw of Combined Mixture (pCi/g)

Nuclides	Case												
	19guti	146guti	156guti	157guti	158guti	159guti	160guti	147guti	161guti	162guti	163guti	164guti	165guti
	Concentration (pCi/g soil)												
U series	11.64	16.27	12.65	10.34	7.58	5.98	4.94	18.76	13.02	9.97	8.08	6.79	5.15
Th series	11.64	8.14	6.32	5.17	3.79	2.99	2.47	6.25	4.34	3.32	2.69	2.26	1.72
excess Ra226	0.00	0.00	6.32	10.34	15.16	17.95	19.77	0.00	8.68	13.30	16.16	18.11	20.60
excess Pb210	0.00	0.00	6.32	10.34	15.16	17.95	19.77	0.00	8.68	13.30	16.16	18.11	20.60

Table 10. *Compute the Radiological Dose Consequent to These Constituent Radionuclide Concentrations*

Mixture	Case												
	19guti	146guti	156guti	157guti	158guti	159guti	160guti	147guti	161guti	162guti	163guti	164guti	165guti
	Radiological Dose (mrem/yr)												
1U + 1Th	25.0												
2U+1Th		25.0											
2U+1Th+1Ra+1Pb			25.0										
2U+1Th+2Ra+2Pb				25.0									
2U+1Th+4Ra+4Pb					25.0								
2U+1Th+6Ra+6Pb						25.0							
2U+1Th+8Ra+8Pb							25.0						
3U+1Th								25.0					
3U+1Th+2Ra+2Pb									25.0				
3U+1Th+4Ra+4Pb										25.0			
3U+1Th+6Ra+6Pb											25.0		
3U+1Th+8Ra+8Pb												25.0	
3U+1Th+12Ra+12Pb													25.0

Table 12. Dose Factor DSR tmax for a Range of Radionuclide Mixtures (mrem/yr)/(pCi/g)

Parameter	Case										
	19guti	146guti	148guti	149guti	150guti	151guti	147guti	152guti	153guti	154guti	155guti
U series	1	2	2	2	2	2	3	3	3	3	3
Th series	1	1	1	1	1	1	1	1	1	1	1
excess Ra226	0	0	1	2	4	6	0	2	5	7	9
Tmax (year)	0	0	40.1	44.7	47.1	48	0	42.8	46	47.2	47.8

Case = RESRAD case identification code
U series = relative concentration of U series in radioactive equilibrium, i.e., U238+DI + 0.0455 U238+DI, in soil entered in RESRAD source .
Th series = relative concentration of Th series in radioactive equilibrium, li.e., Th232+DI in soil entered into RESRAD source
Excess Ra226 = relative concentration of Ra226 in excess of that in U series in soil entered into RESRAD source.
Tmax = time (year) at which maximum total radiological dose occurs after and as a result of radioactive mixture entered into RESRAD at time = 0 year

Radionuclide	Dose Factor DSR tmax (mrem/yr)/(pCi/g)										
Ac227	3.0540E-01	3.0540E-01	8.4900E-02	7.3170E-02	6.7720E-02	6.5750E-02	3.0540E-01	7.7530E-02	7.0110E-02	6.7530E-02	6.6090E-02
Pa231	1.1490E-01	1.1490E-01	3.3060E-01	3.4170E-01	3.4680E-01	3.4860E-01	1.1490E-01	3.3760E-01	3.4450E-01	3.4700E-01	3.4830E-01
Pb210	6.0190E-02	6.0190E-02	1.7320E-02	1.4990E-02	1.3900E-02	1.3510E-02	6.1900E-02	1.5850E-02	1.4380E-02	1.3860E-02	1.3570E-02
Ra226	8.2040E-01	8.2040E-01	8.4740E-01	8.4790E-01	8.4800E-01	8.4800E-01	8.2040E-01	8.4770E-01	8.4790E-01	8.4800E-01	8.4800E-01
Ra228	5.3280E-01	5.3280E-01	1.1020E-02	6.2380E-03	4.6400E-03	4.1450E-03	5.3280E-01	7.8500E-03	5.2970E-03	4.5900E-03	4.2260E-03
Th228	6.2570E-01	6.2570E-01	3.1720E-07	5.8860E-08	2.4520E-08	1.7560E-08	6.2570E-01	1.1340E-07	3.6290E-08	2.3760E-08	1.8600E-08
Th230	6.8260E-03	6.8260E-03	2.1340E-02	2.3040E-02	2.3930E-02	2.4260E-02	6.8260E-03	2.2380E-02	2.3530E-02	2.3960E-02	2.4200E-02
Th232	6.3310E-02	6.3310E-02	1.1930E+00	1.1980E+00	1.1990E+00	1.2000E+00	6.3310E-02	1.1960E+00	1.1990E+00	1.1990E+00	1.2000E+00
U234	3.1930E-03	3.1930E-03	3.0650E-03	3.0510E-03	3.0440E-03	3.0410E-03	3.1930E-03	3.0570E-03	3.0470E-03	3.0440E-03	3.0420E-03
U235	5.8190E-02	5.8190E-02	5.5990E-02	5.5750E-02	5.5620E-02	5.5570E-02	5.8190E-02	5.5840E-02	5.5680E-02	5.5620E-02	5.5580E-02
U238	1.2860E-02	1.2860E-02	1.2330E-02	1.2270E-02	1.2240E-02	1.2220E-02	1.2860E-02	1.2290E-02	1.2250E-02	1.2230E-02	1.2230E-02
U235 +DI	4.7849E-01	4.7849E-01	4.7149E-01	4.7062E-01	4.7014E-01	4.6992E-01	4.7849E-01	4.7097E-01	4.7029E-01	4.7015E-01	4.6997E-01
U238 +DI	9.2524E-01	9.2524E-01	9.2291E-01	9.2266E-01	9.2251E-01	9.2241E-01	9.2695E-01	9.2271E-01	9.2251E-01	9.2249E-01	9.2243E-01
Th232 +DI	1.2218E+00	1.2218E+00	1.2040E+00	1.2042E+00	1.2036E+00	1.2041E+00	1.2218E+00	1.2039E+00	1.2043E+00	1.2036E+00	1.2042E+00

Dose Factor DSR tmax = annual radiological dose contributed per unit radioactivity of individual radionuclide + progeny grown in since introduction at time = 0 year (mrem/yr/(pCi/g)
U235 +DI = DSR referenced to unit radioactivity of parent U235 when the actinium series is in radioactive equilibrium.
U238 +DI = I
Th232 +DI = DSR referenced to unit radioactivity of parent Th232 when the thorium series is in radioactive equilibrium.

Table 13. Ratio of Dose Factor for Series in Case ID -to- Dose Factor for Series in Case 19guti when Each Series is in Radioactive Equilibrium

	19guti	146guti	148guti	149guti	150guti	151guti	147guti	152guti	153guti	154guti	155guti
Ratio U235 +DI	1.00	1.00	0.99	0.98	0.98	0.98	1.00	0.98	0.98	0.98	0.98
Ratio U238 +DI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ratio Th232 +DI	1.00	1.00	0.99	0.99	0.99	0.99	1.00	0.99	0.99	0.99	0.99
Ratio Ra226	1.00	1.00	1.03	1.03	1.03	1.03	1.00	1.03	1.03	1.03	1.03

Ratio U235 +DI = ratio of dose factor for U235 series in identified case -to- dose factor in U235 series in case 19guti when each series is initially in radioactive equilibrium.
Ratio U238 +DI = ratio of dose factor for U238 series + U235 series in natural U ratio -to- U238 series + U235 series in nat
Ratio Th232 +DI = ratio of dose factor for Th232 series in identified case -to- dose factor in Th232 series in case 19guti when each series is initially in radioactive equilibrium

Table 14. Fraction of Total Dose Factor in U series in Radioactive Equilibrium that is Attributable to Ra226

	19guti	146guti	148guti	149guti	150guti	151guti	147guti	152guti	153guti	154guti	155guti
Ra226/U238+DI	0.89	0.89	0.92	0.92	0.92	0.92	0.89	0.92	0.92	0.92	0.92

Table 15. Dose Caused by Sum of Key Radionuclides in Mixture (mrem/yr)

	19guti	146guti	148guti	149guti	150guti	151guti	147guti	152guti	153guti	154guti	155guti
1U + 1 Th	2.1471E+00	2.1471E+00	2.1269E+00	2.1269E+00	2.1261E+00	2.1266E+00	2.1488E+00	2.1266E+00	2.1268E+00	2.1261E+00	2.1267E+00
2U + 1Th	3.072E+00	3.072E+00	3.050E+00	3.050E+00	3.049E+00	3.049E+00	3.076E+00	3.049E+00	3.049E+00	3.049E+00	3.049E+00
2U+1Th+1Ra			3.897E+00								
2U+1Th+2Ra				4.745E+00							
2U+1Th+4Ra					6.441E+00						
2U+1Th+6Ra						8.137E+00					
3U+1Th	3.998E+00	3.998E+00	3.973E+00	3.972E+00	3.971E+00	3.971E+00	4.003E+00	3.972E+00	3.972E+00	3.971E+00	3.972E+00
3U+1Th+2Ra								5.6674E+00			
3U+1Th+5Ra									8.2113E+00		
3U+1Th+7Ra										9.9070E+00	
3U+1Th+9Ra											1.1604E+01

2U+1Th+1Ra = 2 U series (incl U235 series in Unat) + 1 Th series + 1 Ra in excess of U series rad equilibrium.

Table 16. Dose Caused per Unit Radioactivity of Key Radionuclides in Mixture (mrem/yr)/(pCi/g)

	19guti	146guti	148guti	149guti	150guti	151guti	147guti	152guti	153guti	154guti	155guti
1U + 1Th	1.07E+00	1.07E+00	1.06E+00	1.06E+00	1.06E+00	1.06E+00	1.07E+00	1.06E+00	1.06E+00	1.06E+00	1.06E+00
2U + 1Th	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.03E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00
2U+1Th+1Ra			9.74E-01								
2U+1Th+2Ra				9.49E-01							
2U+1Th+4Ra					9.20E-01						
2U+1Th+6Ra						9.04E-01					
3U+1Th	9.99E-01	9.99E-01	9.93E-01	9.93E-01	9.93E-01	9.93E-01	1.00E+00	9.93E-01	9.93E-01	9.93E-01	9.93E-01
3U+1Th+2Ra								9.45E-01			
3U+1Th+5Ra									9.12E-01		
3U+1Th+7Ra										9.09E-02	
3U+1Th+9Ra											8.93E-01

2U+1Th+1Ra = 2 U series (incl U235 series in Unat) + 1 Th series + 1 Ra in excess of U series rad equilibrium.

Table 17. DCGLw Derived at Time of Maximum Total Dose from Radionuclide Mixture

Case	19guti	146guti	148guti	149guti	150guti	151guti	147guti	152guti	153guti	154guti	155guti
U series	1	2	2	2	2	2	3	3	3	3	3
Th series	1	1	1	1	1	1	1	1	1	1	1
excess Ra226	0	0	1	2	4	6	0	2	5	7	9
Tmax (year)	0	0	40.1	44.7	47.1	48	0	42.8	46	47.2	47.8
Radionuclide	DCGLw (pCi/g)										
Ac227	8.1860E+01	8.1860E+01	2.9446E+02	3.4167E+02	3.6917E+02	3.8023E+02	8.1860E+01	3.2246E+02	3.5658E+02	3.7021E+02	3.7827E+02
Pa231	2.1758E+02	2.1758E+02	7.5620E+01	7.3164E+01	7.2088E+01	7.1715E+01	2.1758E+02	7.4052E+01	7.2569E+01	7.2046E+01	7.1777E+01
Pb210	4.1535E+02	4.1535E+02	1.4434E+03	1.6678E+03	1.7986E+03	1.8505E+03	4.0388E+02	1.5773E+03	1.7385E+03	1.8038E+03	1.8423E+03
Ra226	3.0473E+01	3.0473E+01	2.9502E+01	2.9485E+01	2.9481E+01	2.9481E+01	3.0473E+01	2.9492E+01	2.9485E+01	2.9481E+01	2.9481E+01
Ra228	4.6922E+01	4.6922E+01	2.2686E+03	4.0077E+03	5.3879E+03	6.0314E+03	4.6922E+01	3.1847E+03	4.7197E+03	5.4466E+03	5.9158E+03
Th228	3.9955E+01	3.9955E+01	7.8815E+07	4.2474E+08	1.0196E+09	1.4237E+09	3.9955E+01	2.2046E+08	6.8890E+08	1.0522E+09	1.3441E+09
Th230	3.6625E+03	3.6625E+03	1.1715E+03	1.0851E+03	1.0447E+03	1.0305E+03	3.6625E+03	1.1171E+03	1.0625E+03	1.0434E+03	1.0331E+03
Th232	3.9488E+02	3.9488E+02	2.0956E+01	2.0868E+01	2.0851E+01	2.0833E+01	3.9488E+02	2.0903E+01	2.0851E+01	2.0851E+01	2.0833E+01
U234	7.8296E+03	7.8296E+03	8.1566E+03	8.1940E+03	8.2129E+03	8.2210E+03	7.8296E+03	8.1780E+03	8.2048E+03	8.2129E+03	8.2183E+03
U235	4.2963E+02	4.2963E+02	4.4651E+02	4.4843E+02	4.4948E+02	4.4988E+02	4.2963E+02	4.4771E+02	4.4899E+02	4.4948E+02	4.4980E+02
U238	1.9440E+03	1.9440E+03	2.0276E+03	2.0375E+03	2.0425E+03	2.0458E+03	1.9440E+03	2.0342E+03	2.0408E+03	2.0442E+03	2.0442E+03
U235 +DI	5.2248E+01	5.2248E+01	5.3023E+01	5.3121E+01	5.3176E+01	5.3201E+01	5.2248E+01	5.3082E+01	5.3159E+01	5.3175E+01	5.3195E+01
U238 +DI	2.7020E+01	2.7020E+01	2.7088E+01	2.7095E+01	2.7100E+01	2.7103E+01	2.6970E+01	2.7094E+01	2.7100E+01	2.7101E+01	2.7102E+01
Th232 +DI	2.0461E+01	2.0461E+01	2.0764E+01	2.0760E+01	2.0770E+01	2.0762E+01	2.0461E+01	2.0767E+01	2.0759E+01	2.0771E+01	2.0760E+01

U235 +DI = DCGLw+A99 referenced to unit radioactivity of parent U235 when the actinium series is in radioactive equilibrium.
U238 +DI = DCGLw of U series in radioactive equilibrium + actiniun
Th232 +DI = DCGLw referenced to unit radioactivity of parent Th232 when the thorium series is in radioactive equilibrium.

Table 18. DCGLw of Combined Mixture of U Series + Th Series + Ra226 in Excess of U Series

case:	19guti	146guti	148guti	149guti	150guti	151guti	147guti	152guti	153guti	154guti	155guti
Mixture	DCGLw of Combined Mixture (pCi total/g)										
1U + 1Th	23.3										
2U+1Th		24.4									
2U+1Th+1Ra			25.7								
2U+1Th+2Ra				26.3							
2U+1Th+4Ra					27.2						
2U+1Th+6Ra						27.7					
3U+1Th							25.0				
3U+1Th+2Ra								26.5			
3U+1Th+5Ra									27.4		
3U+1Th+7Ra										27.8	
3U+1Th+9Ra											28.0

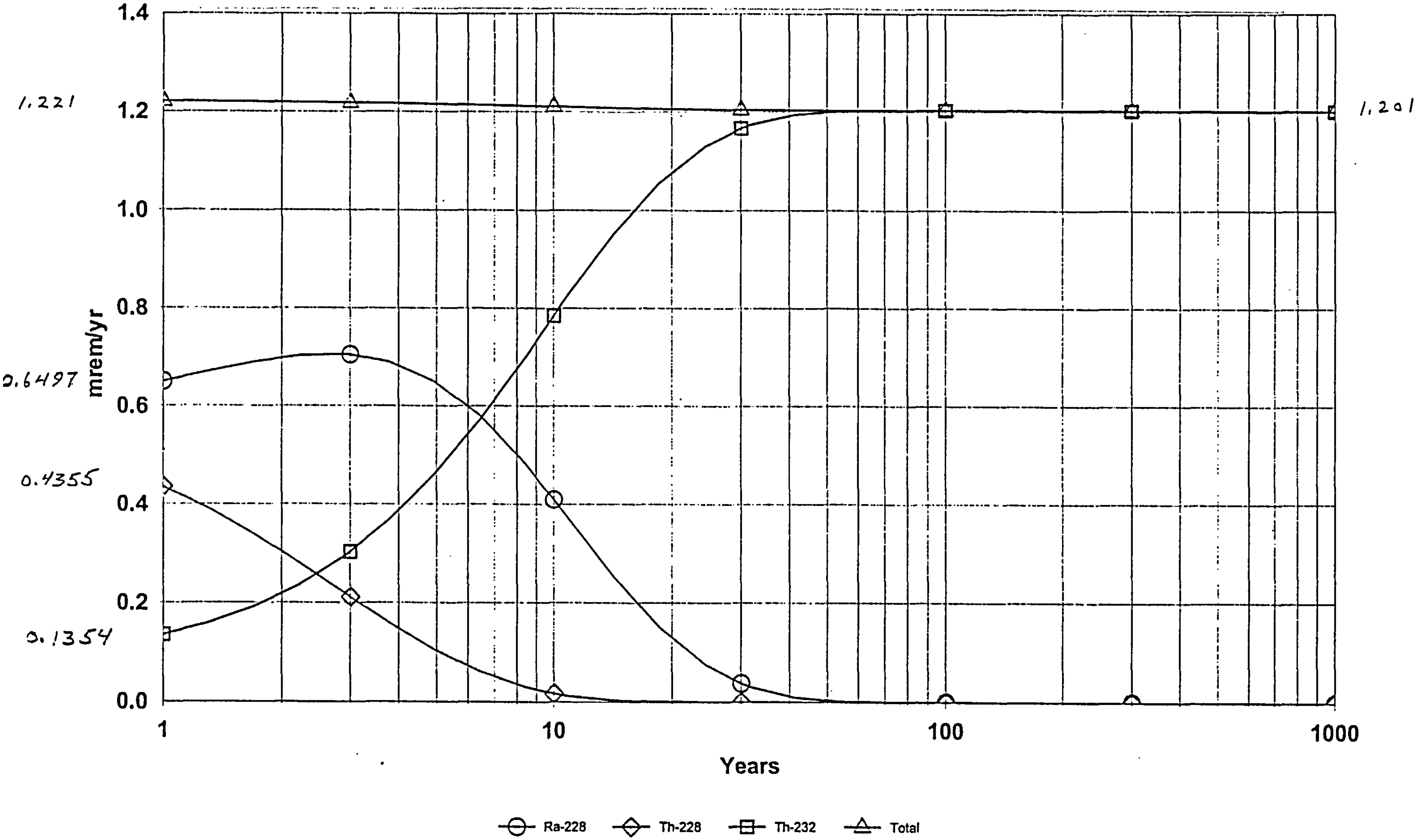
Table 19. Concentration of Each Constituent Radionuclide Series in DCGLw of Combined Mixture (pCi/g)

Nuclides	Case										
	19guti	146guti	148guti	149guti	150guti	151guti	147guti	152guti	153guti	154guti	155guti
	Concentration (pCi/g soil)										
U series	11.64	16.27	12.83	10.54	7.76	6.14	18.74	13.23	9.13	7.57	6.46
Th series	11.64	8.14	6.41	5.27	3.88	3.07	6.25	4.41	3.04	2.52	2.15
Ra226	0.00	0.00	6.41	10.54	15.53	18.43	0.00	8.82	15.22	17.66	19.39

Table 20. Compute the Radiological Dose Consequent to These Constituent Radionuclide Concentrations

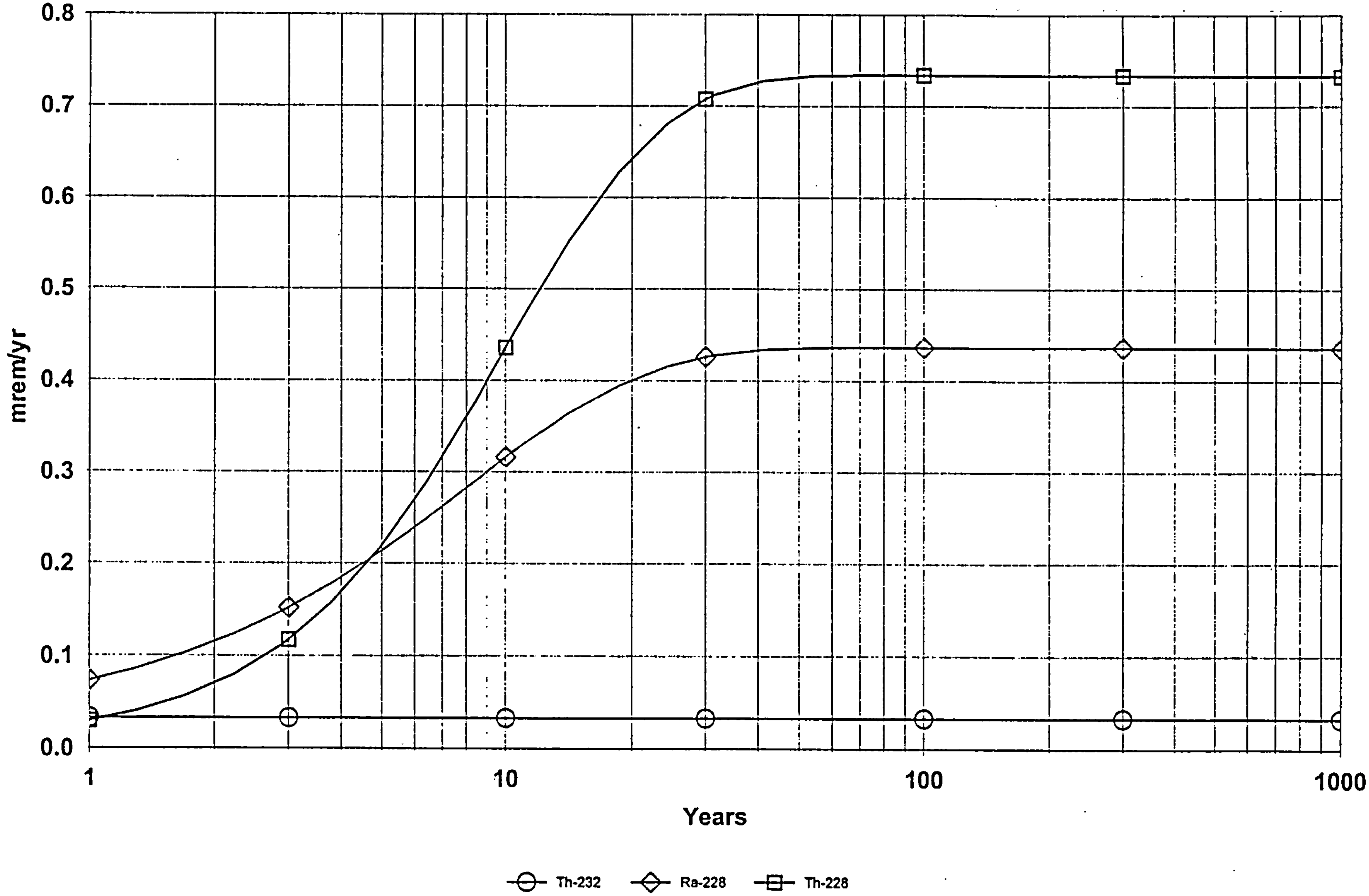
Mixture	Case										
	19guti	146guti	148guti	149guti	150guti	151guti	147guti	152guti	153guti	154guti	155guti
	Radiological Dose (mrem/yr)										
1U + 1Th	2.5000E+01										
2U+1Th		2.5000E+01									
2U+1Th+1Ra			2.5000E+01								
2U+1Th+2Ra				2.5000E+01							
2U+1Th+4Ra					2.5000E+01						
2U+1Th+6Ra						2.5000E+01					
3U+1Th							2.5000E+01				
3U+1Th+2Ra								2.5000E+01			
3U+1Th+5Ra									2.5000E+01		
3U+1Th+7Ra										2.5000E+01	
3U+1Th+9Ra											2.5000E+01

Figure 168C. Th^{232}, Ra^{228}, and Th^{228} Parents and Total



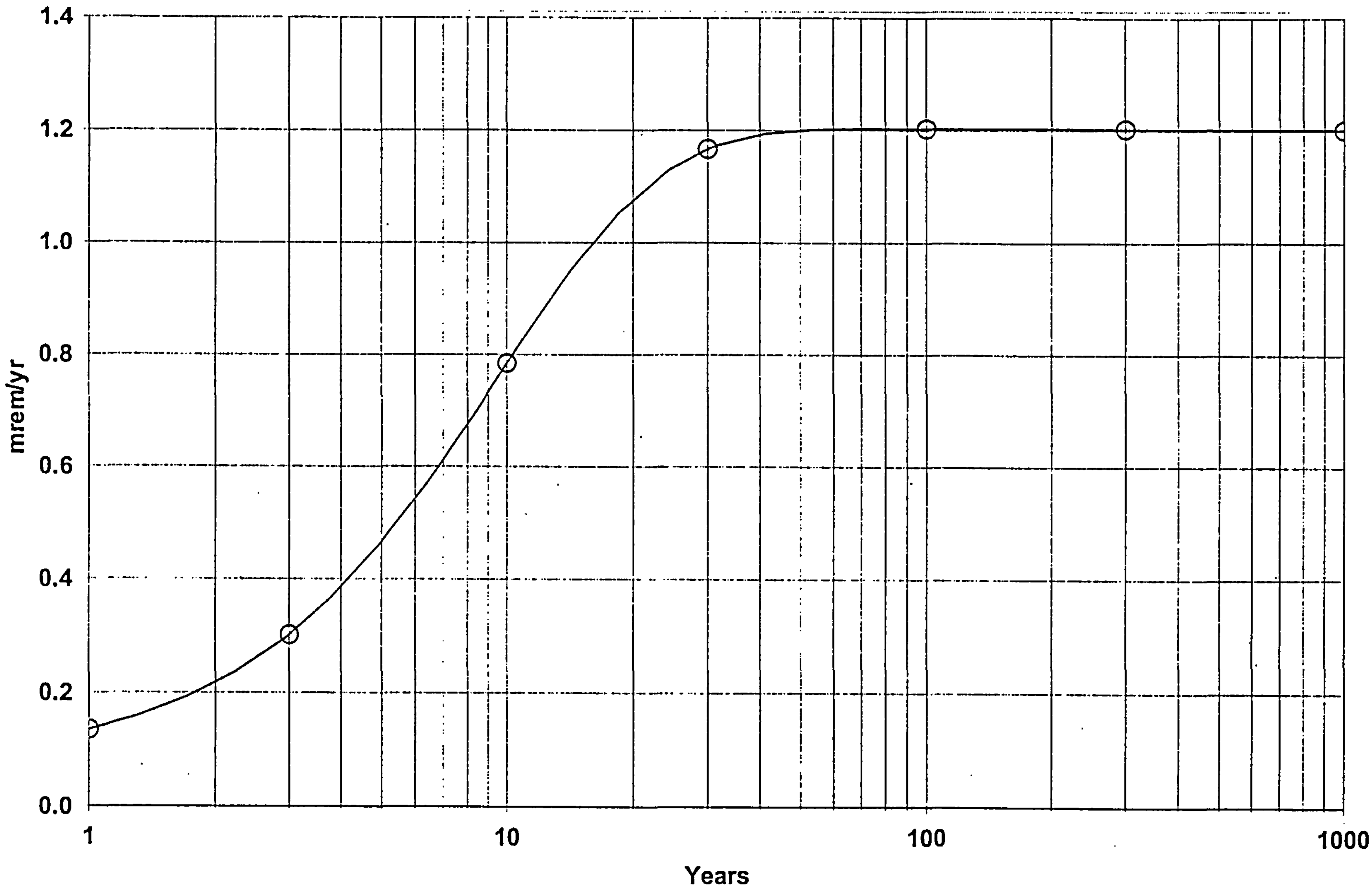
168gtirae.RAD 02/28/2005 13:02 Includes All Pathways

Figure 169A. Th^{232} Parent with Progeny Growing



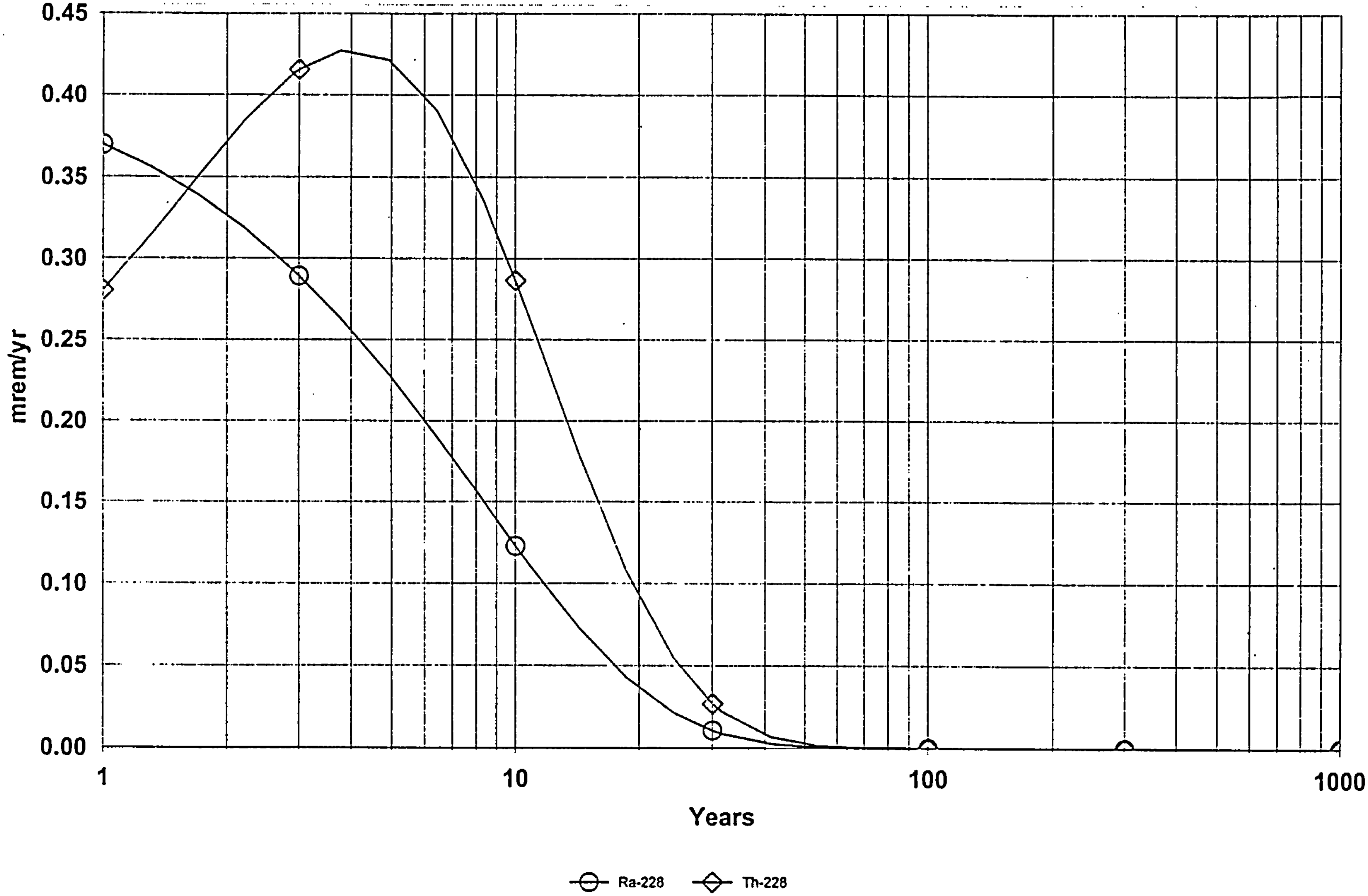
169gtirae.RAD 02/28/2005 21:54 Includes All Pathways

Figure 169B. Th^{232} Parent and Progeny Summed



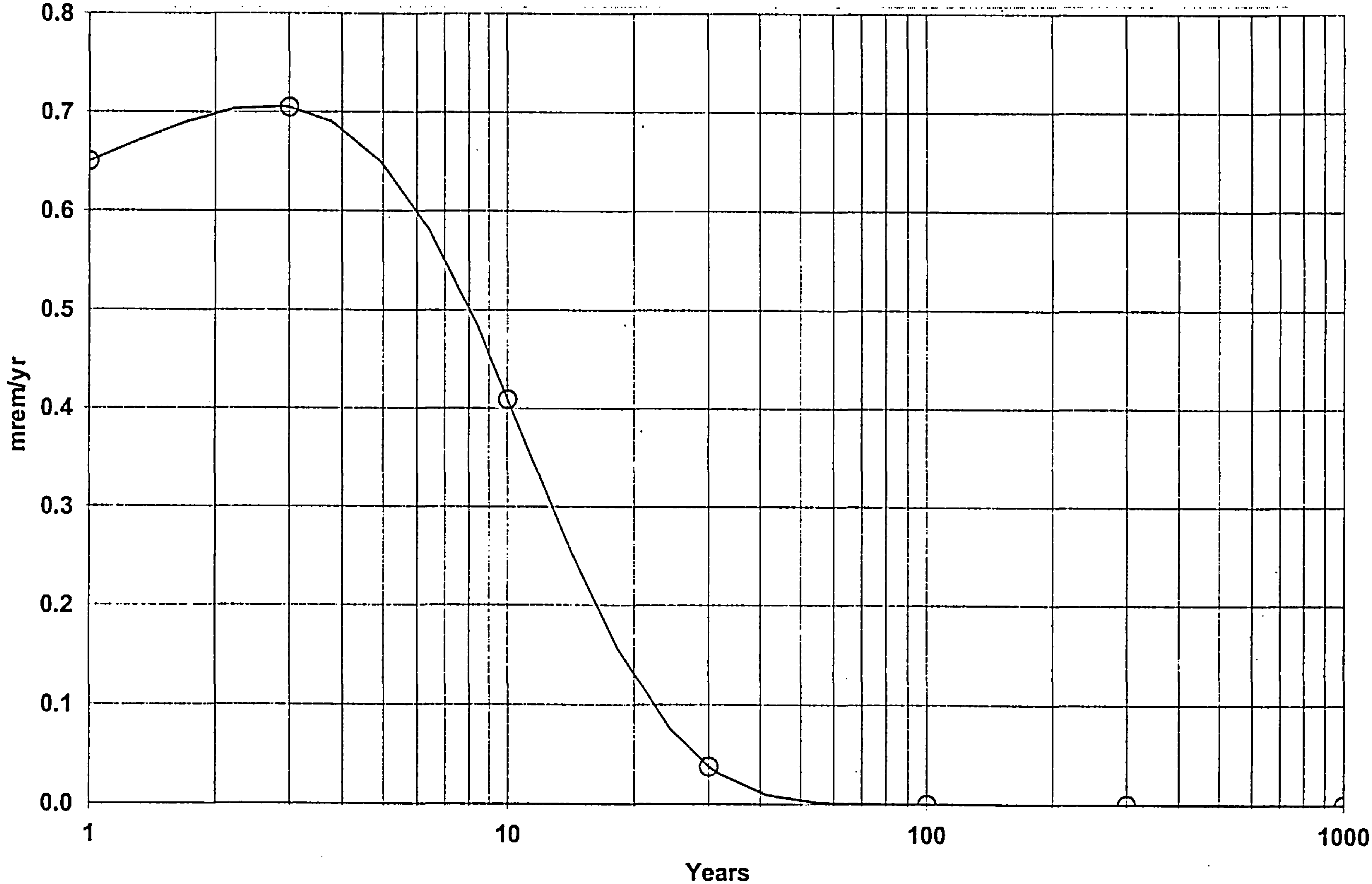
169gtirae.RAD 02/28/2005 21:54 Includes All Pathways

Figure 170A. Ra^{228} PARENT WITH PROGENY GROWING



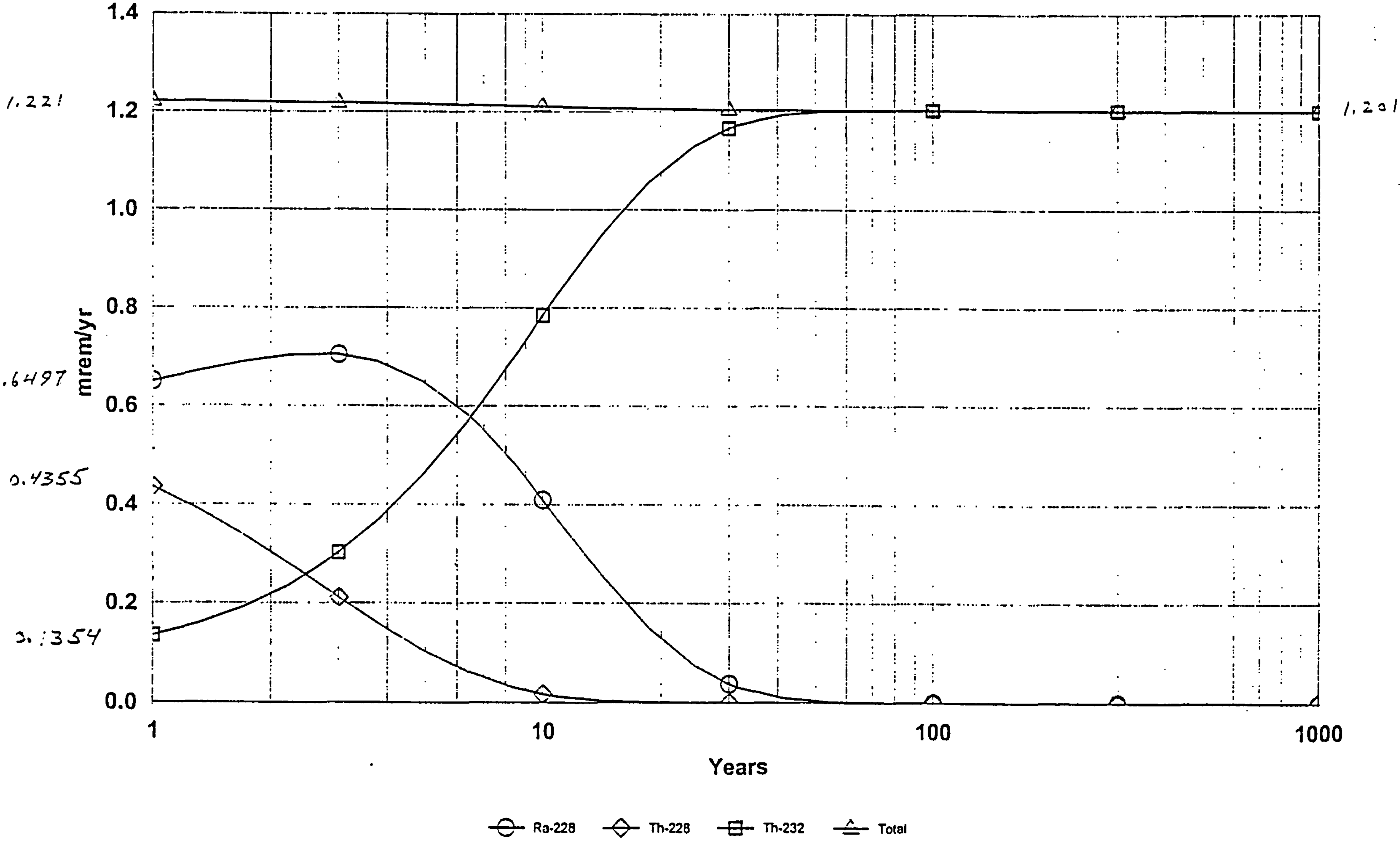
170gtirae.RAD 03/01/2005 09:07 Includes All Pathways

Figure 170B. Ra^{228} Parent and Progeny Summed



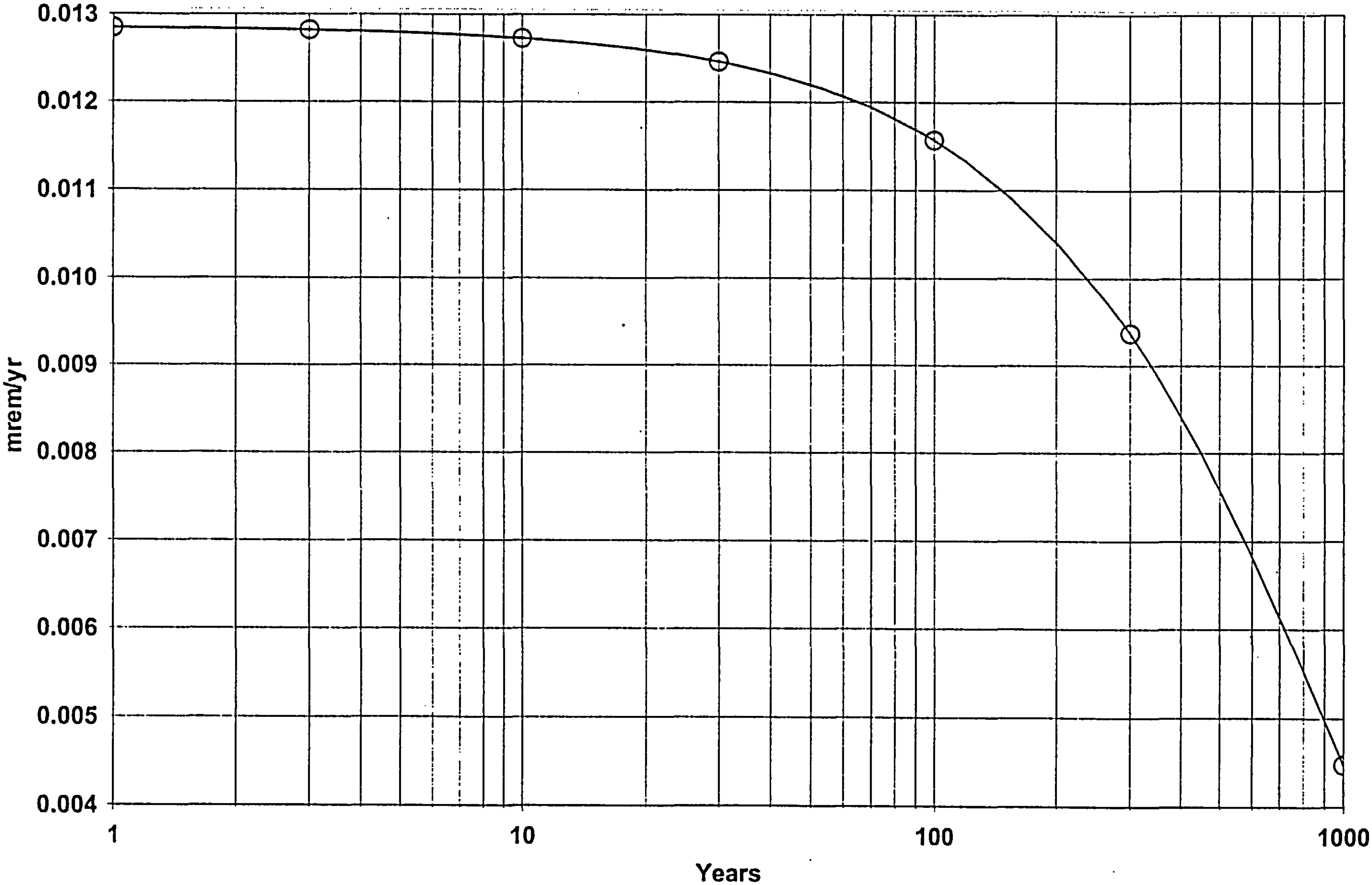
170gtirae.RAD 03/01/2005 09:34 Includes All Pathways

Figure 168C. Th^{232}, Ra^{228}, and Th^{228} Parents and Total



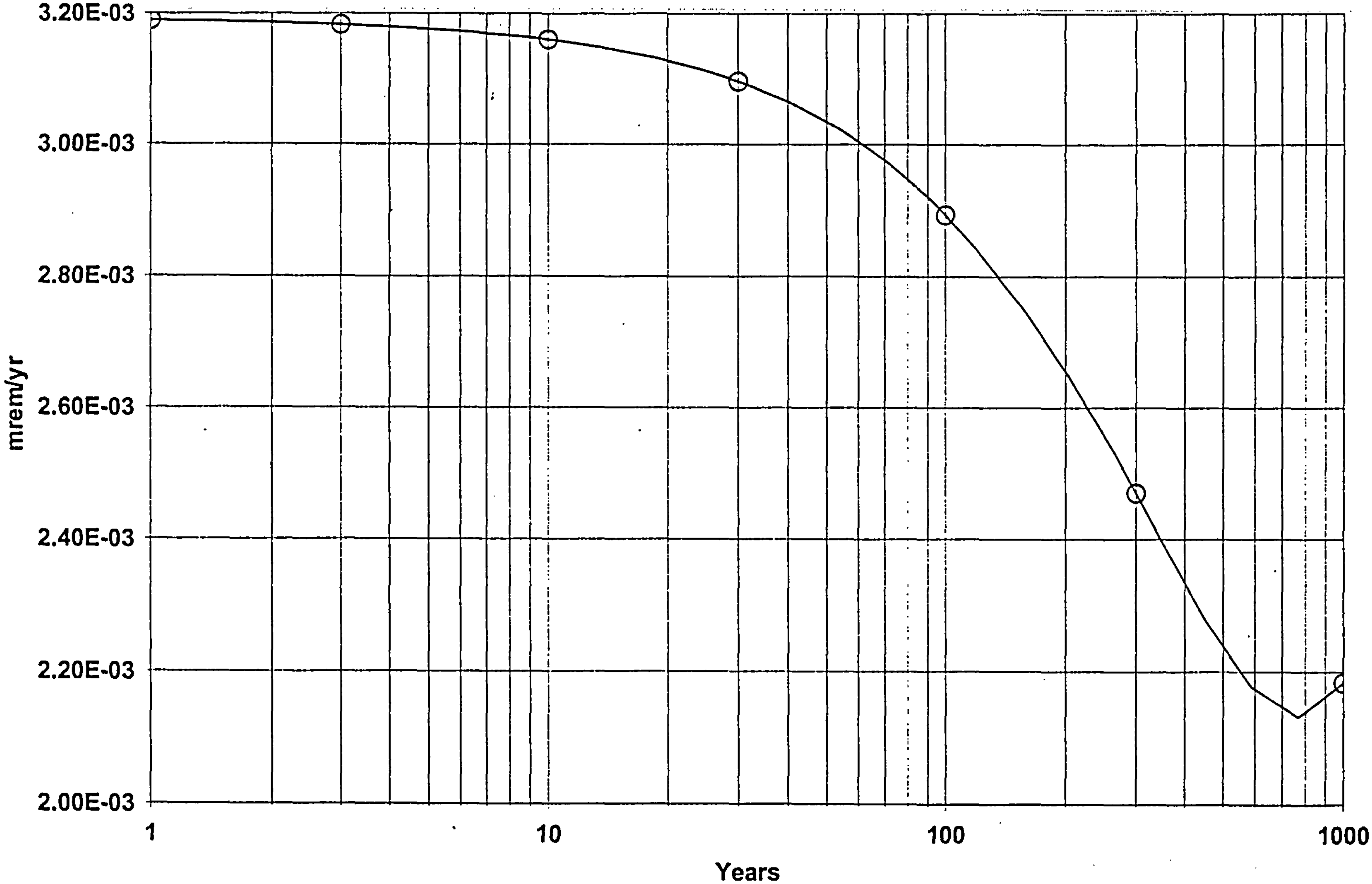
168gtirae.RAD 02/28/2005 13:02 Includes All Pathways

Figure 173B. U^{238} Parent and Progeny Summed



173guirae.RAD 03/01/2005 14:00 Includes All Pathways

Figure 173C. U^{234} Parent and Progeny Summed



173guirae.RAD 03/01/2005 14:00 Includes All Pathways

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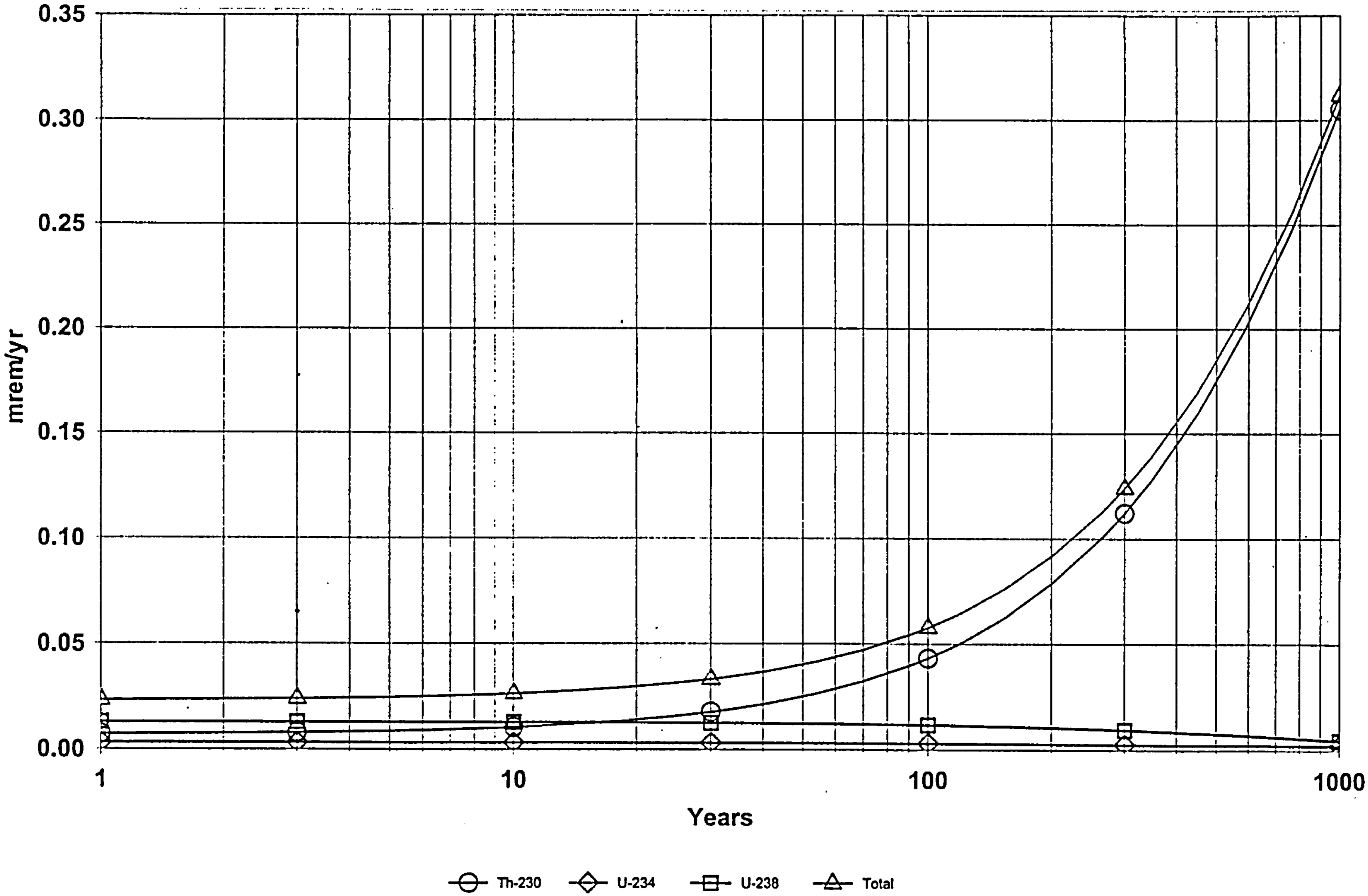
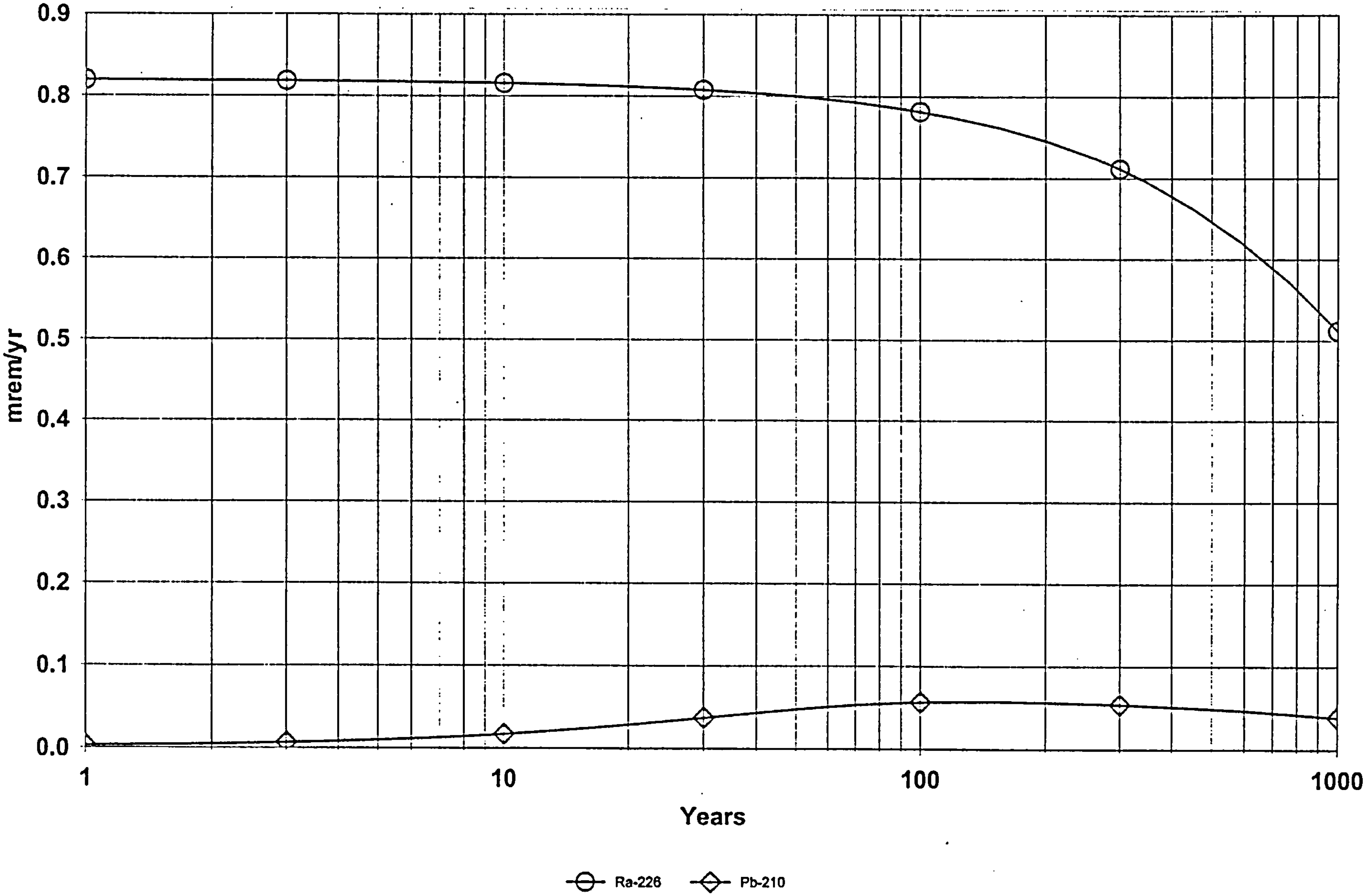
Figure 172D. U^{238}, U^{234}, and Th^{230} Parents and Total



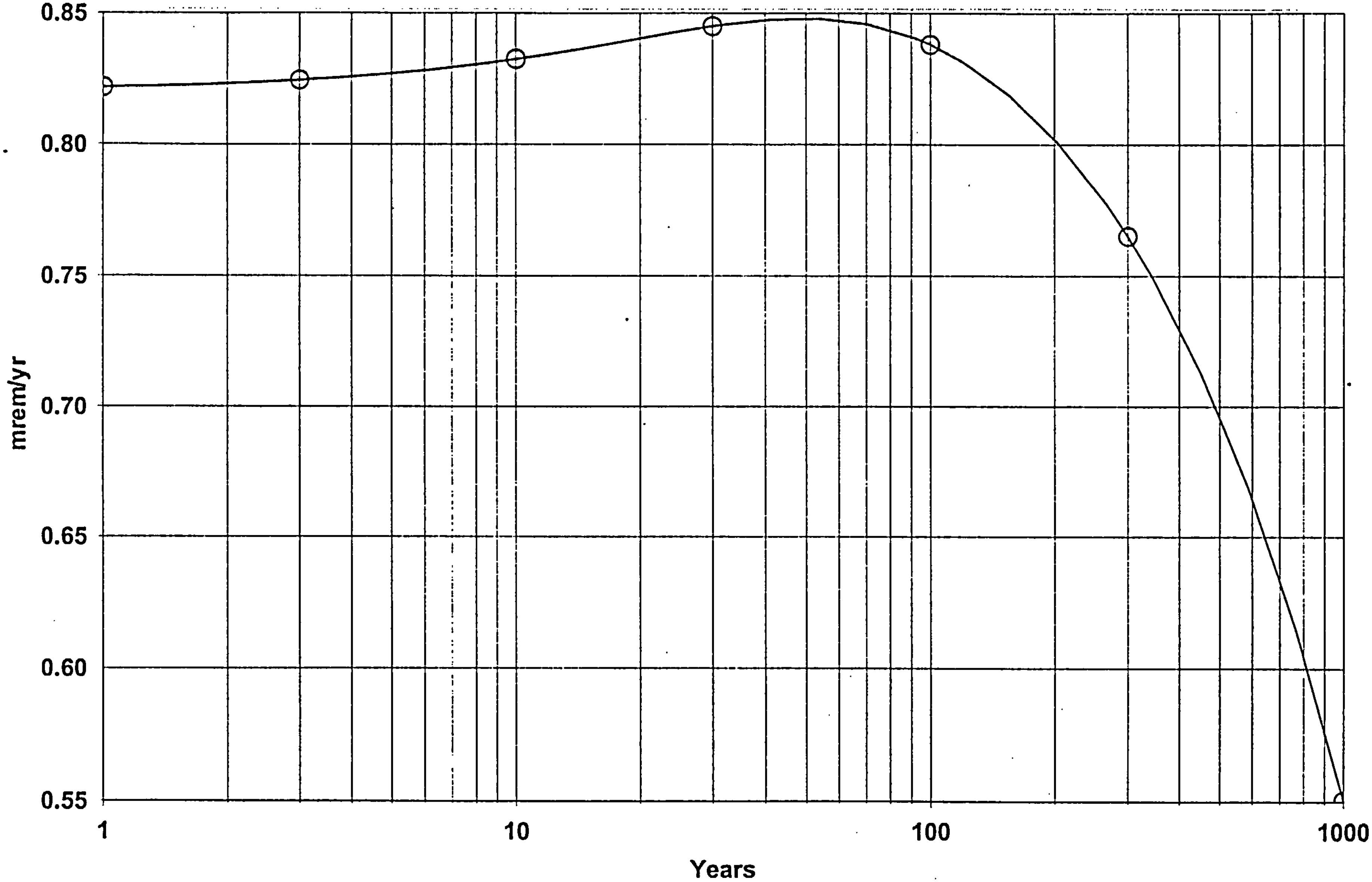
172guirae.RAD 03/01/2005 15:56 Includes All Pathways

Figure 171A. Ra^{226} Parent with Progeny Growing



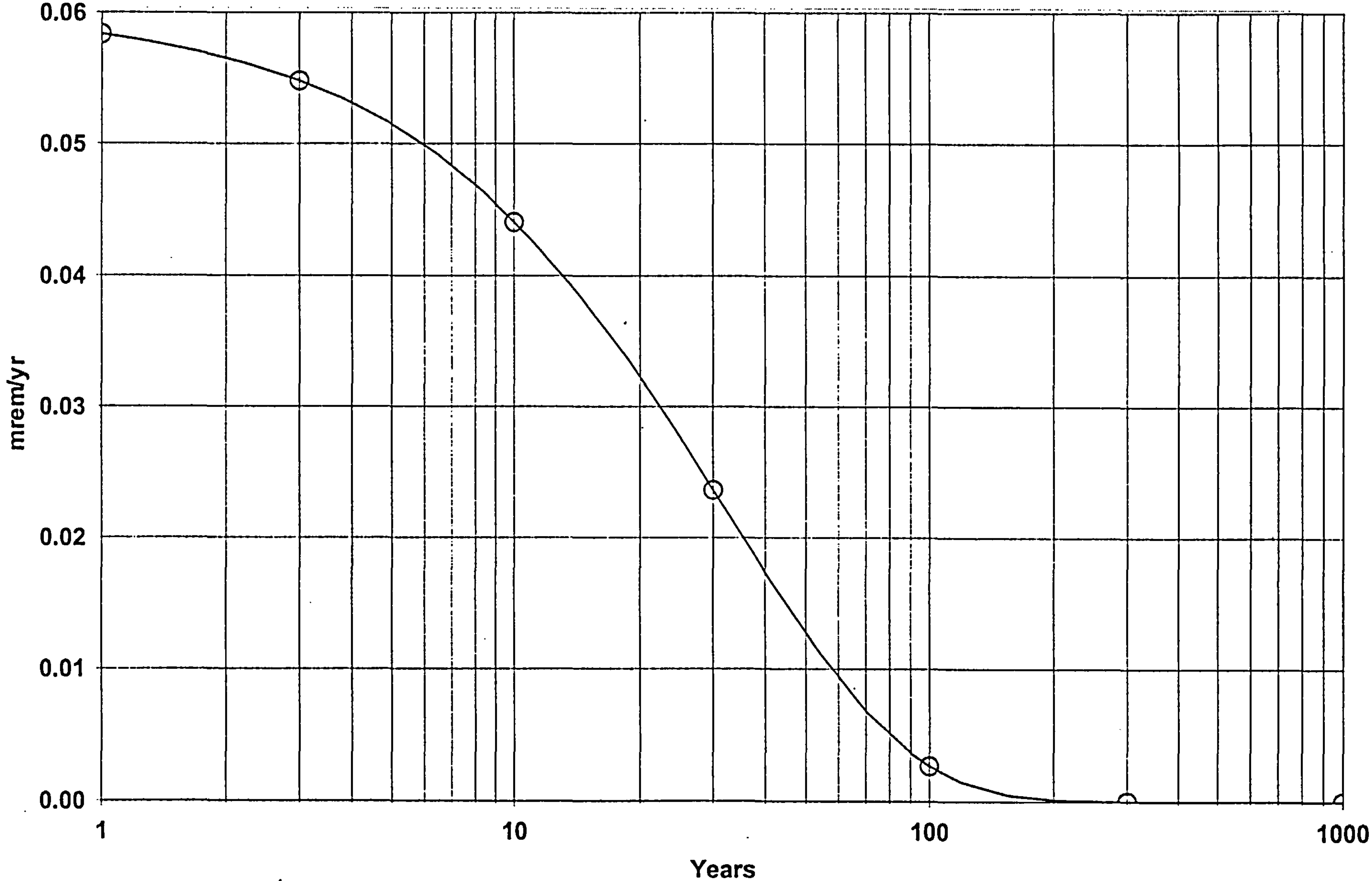
171guirae.RAD 03/01/2005 13:23 Includes All Pathways

Figure 171B. Ra^{226} Parent with Progeny Summed



171guirae.RAD 03/01/2005 13:23 Includes All Pathways

Figure 171C. Pb^{210} Parent with Progeny



171guirae.RAD 03/01/2005 13:23 Includes All Pathways

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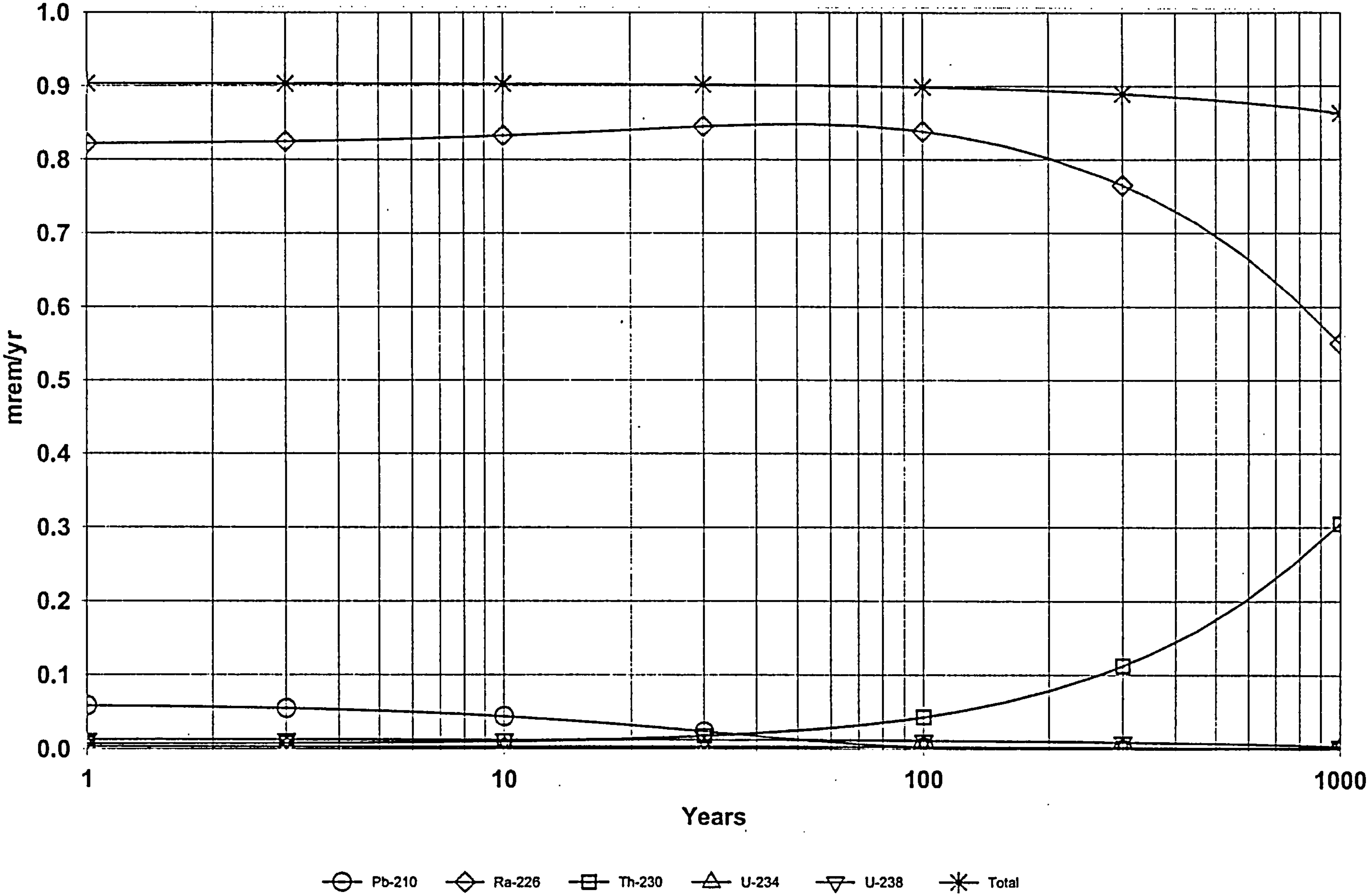
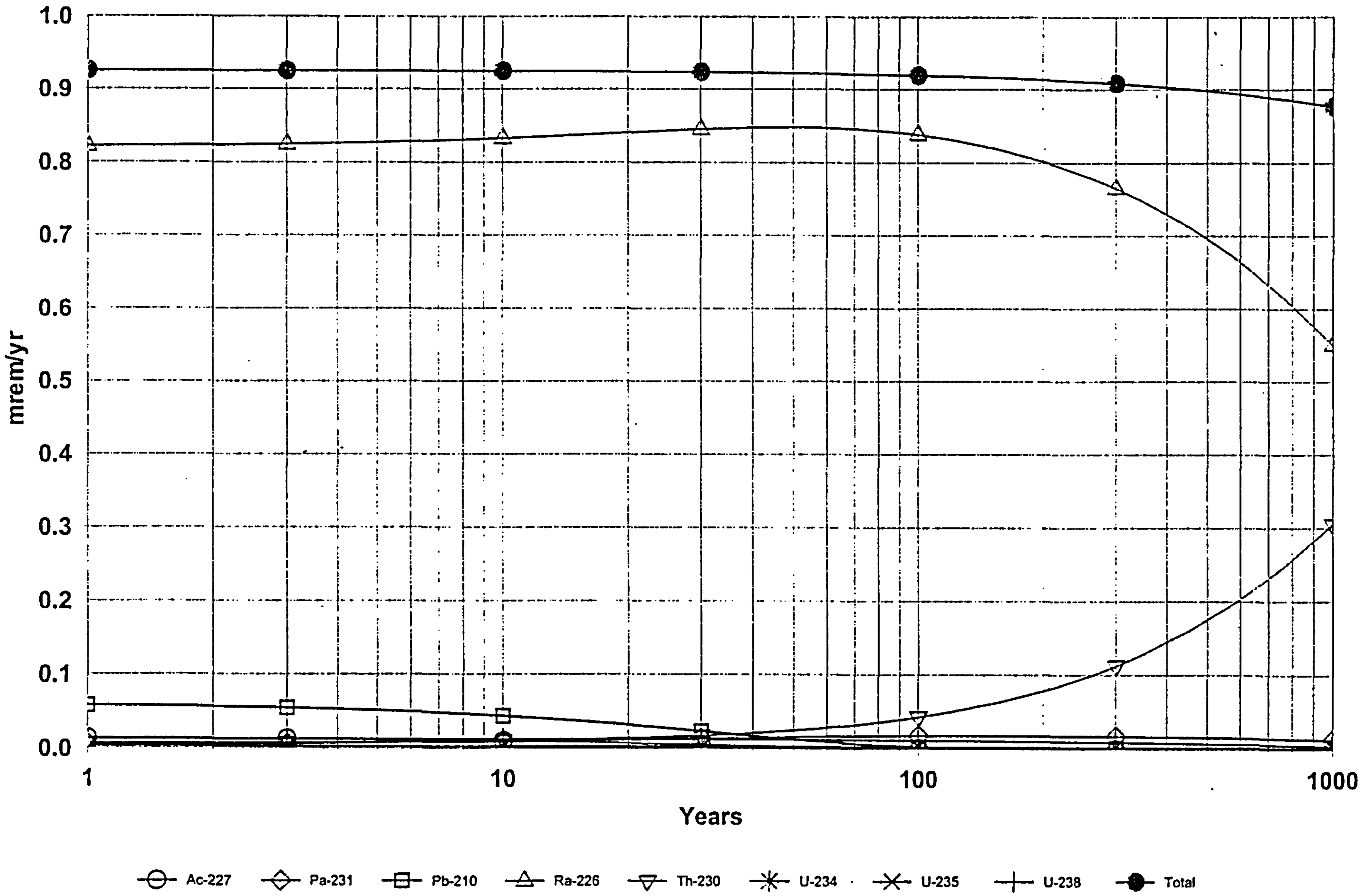
Figure 171D. U Series



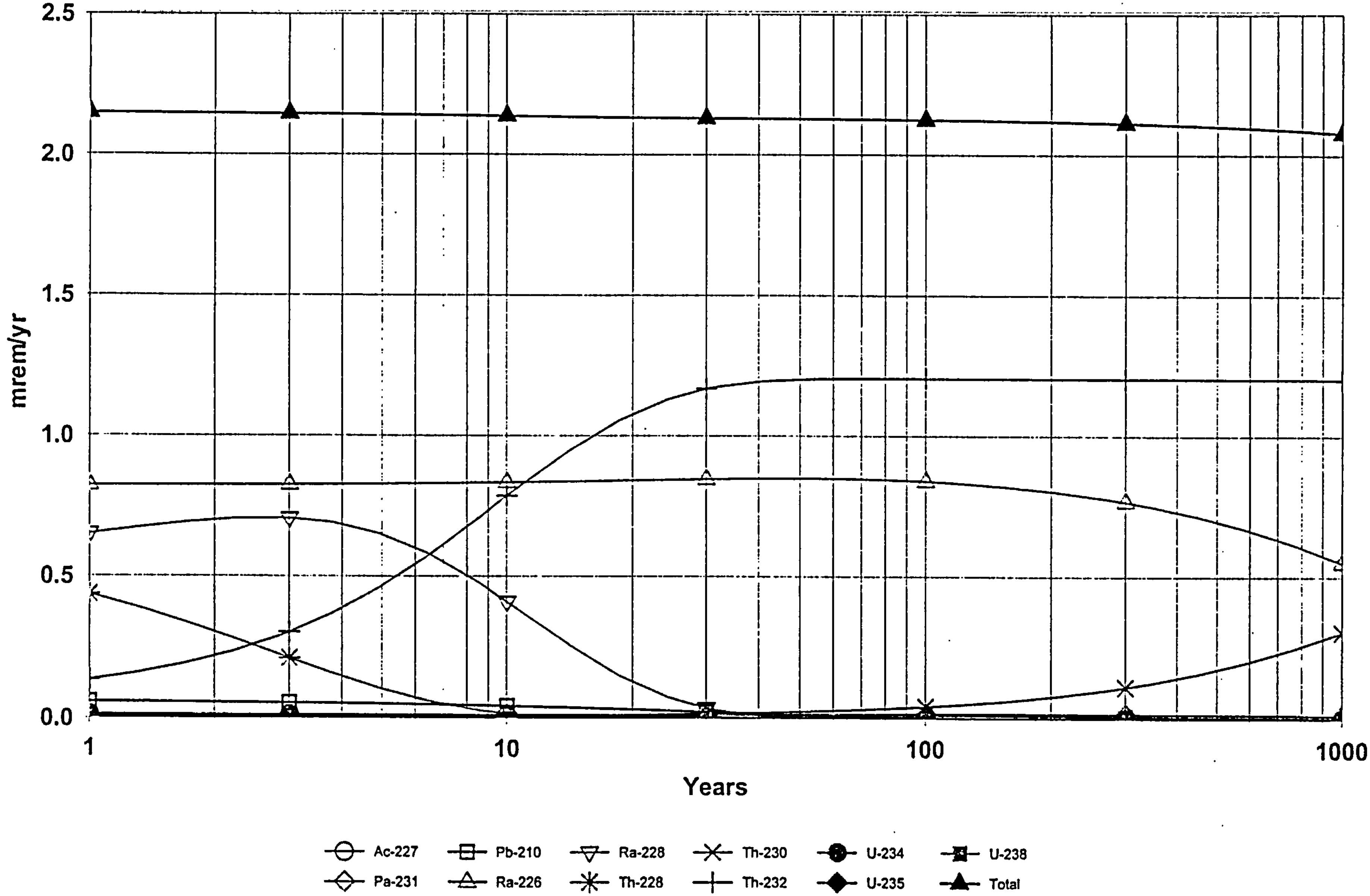
171guirae.RAD 03/01/2005 13:23 Includes All Pathways

Figure 167A. U Series + 0.0455 U^{235} Series



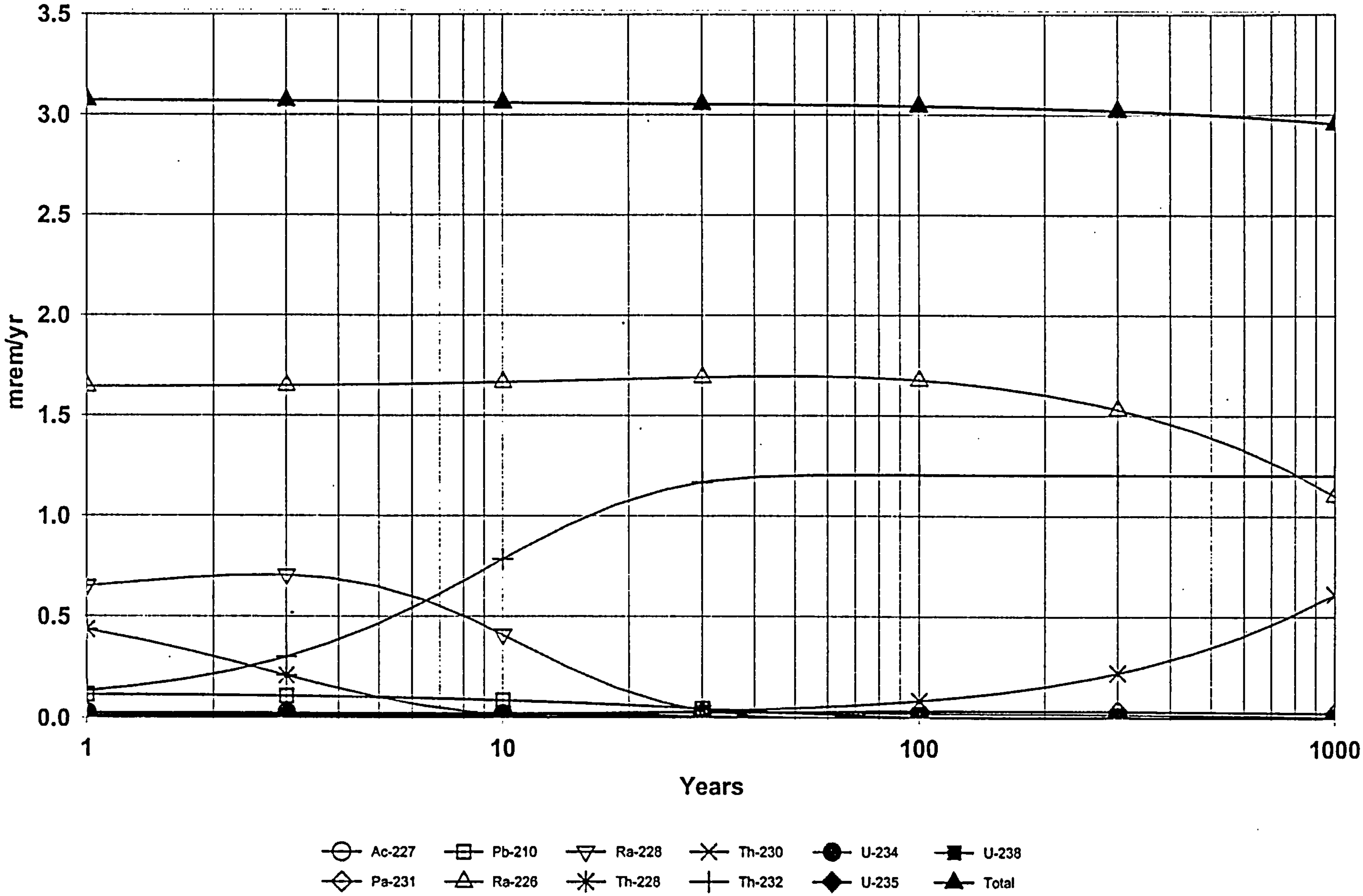
167guirae.RAD 02/28/2005 12:55 Includes All Pathways

Figure 19A. U Series + 0.0455 U^{235} Series + 1 Th Series



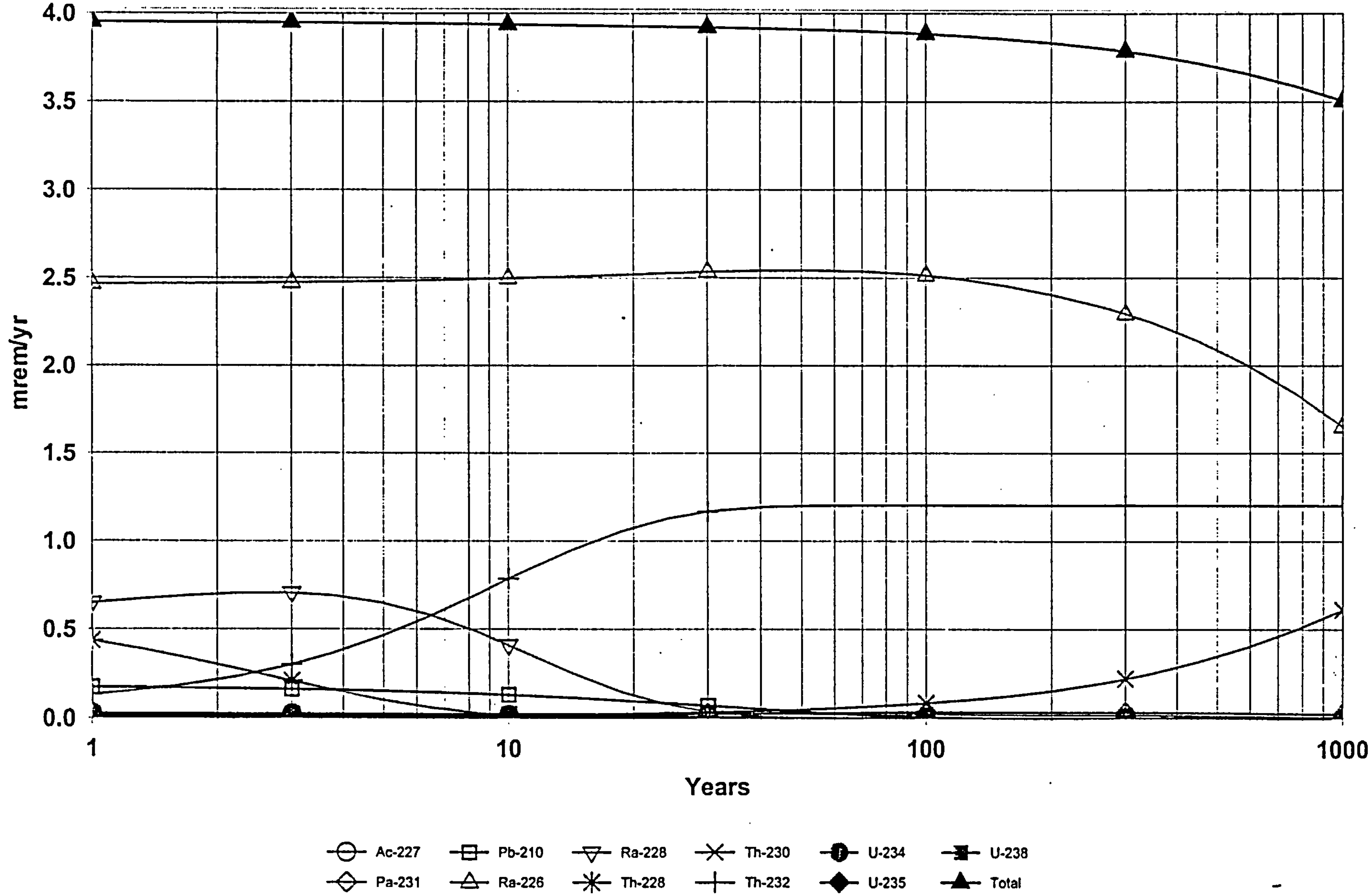
19gutl.RAD 03/03/2005 12:59 Includes All Pathways

Figure 146A. 2 U Series + 0.0910 U^{235} Series + 1 Th Series



146guti.RAD 02/23/2005 13:52 Includes All Pathways

Figure 156A. 2 U Series + 0.0910 U^{235} Series + 1 Excess Ra^{226} + 1 Excess Pb^{210} + 1 Th Series



156guti.RAD 02/26/2005 20:36 Includes All Pathways

Figure 157A. 2 U Series + 0.0910 U^{235} Series + 2 Excess Ra^{226} + 2 Excess Pb^{210} + 1 Th Series

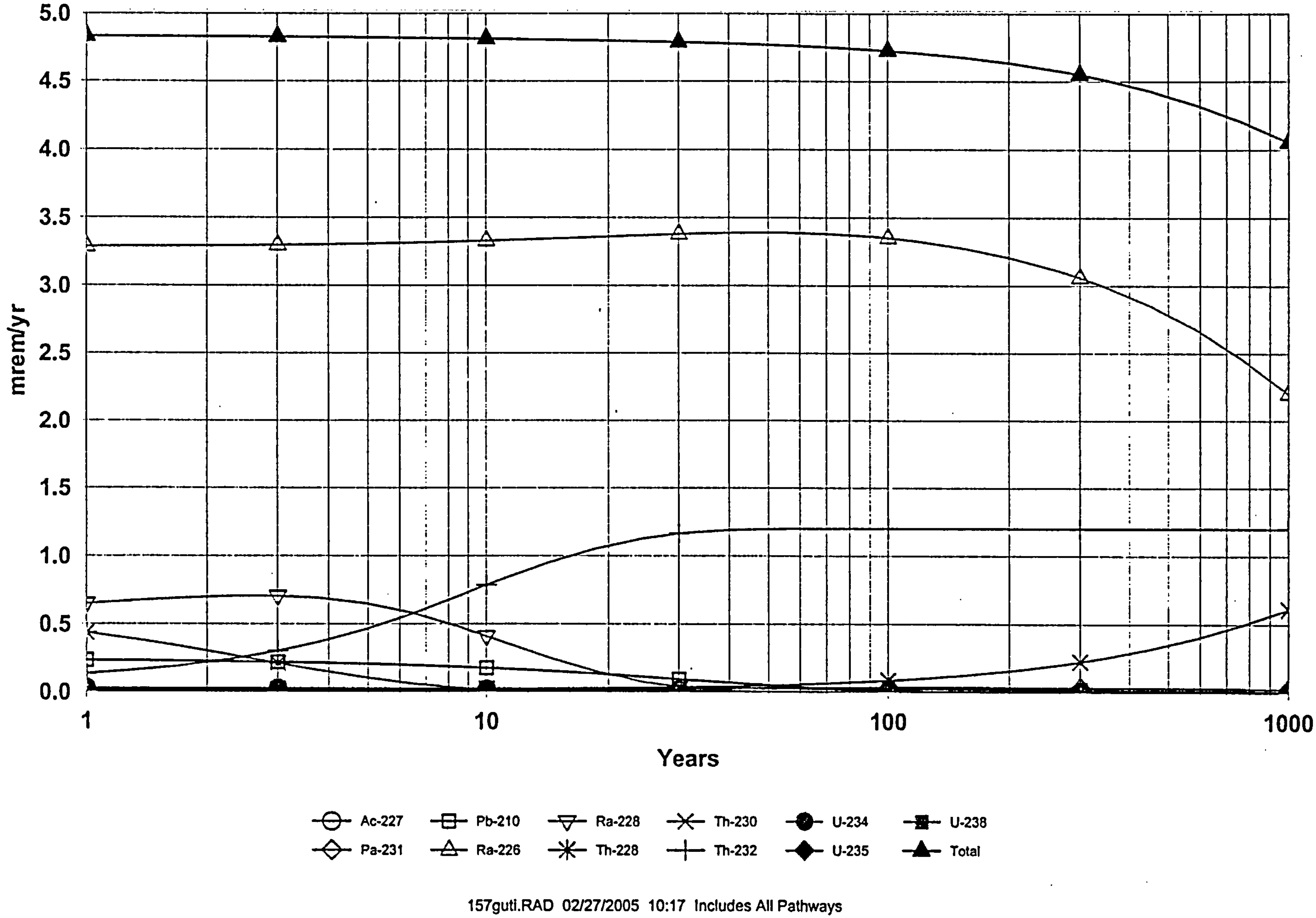
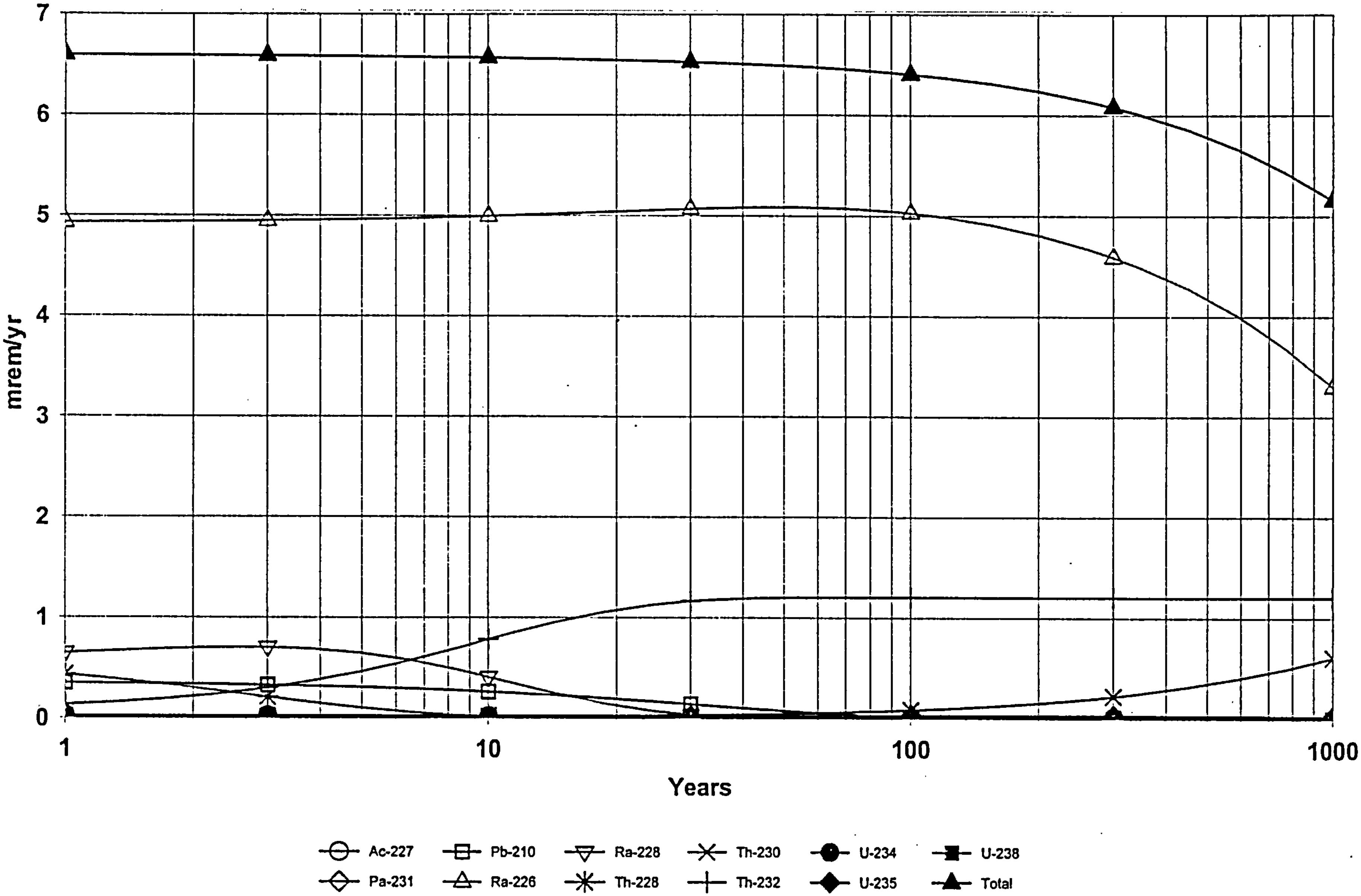


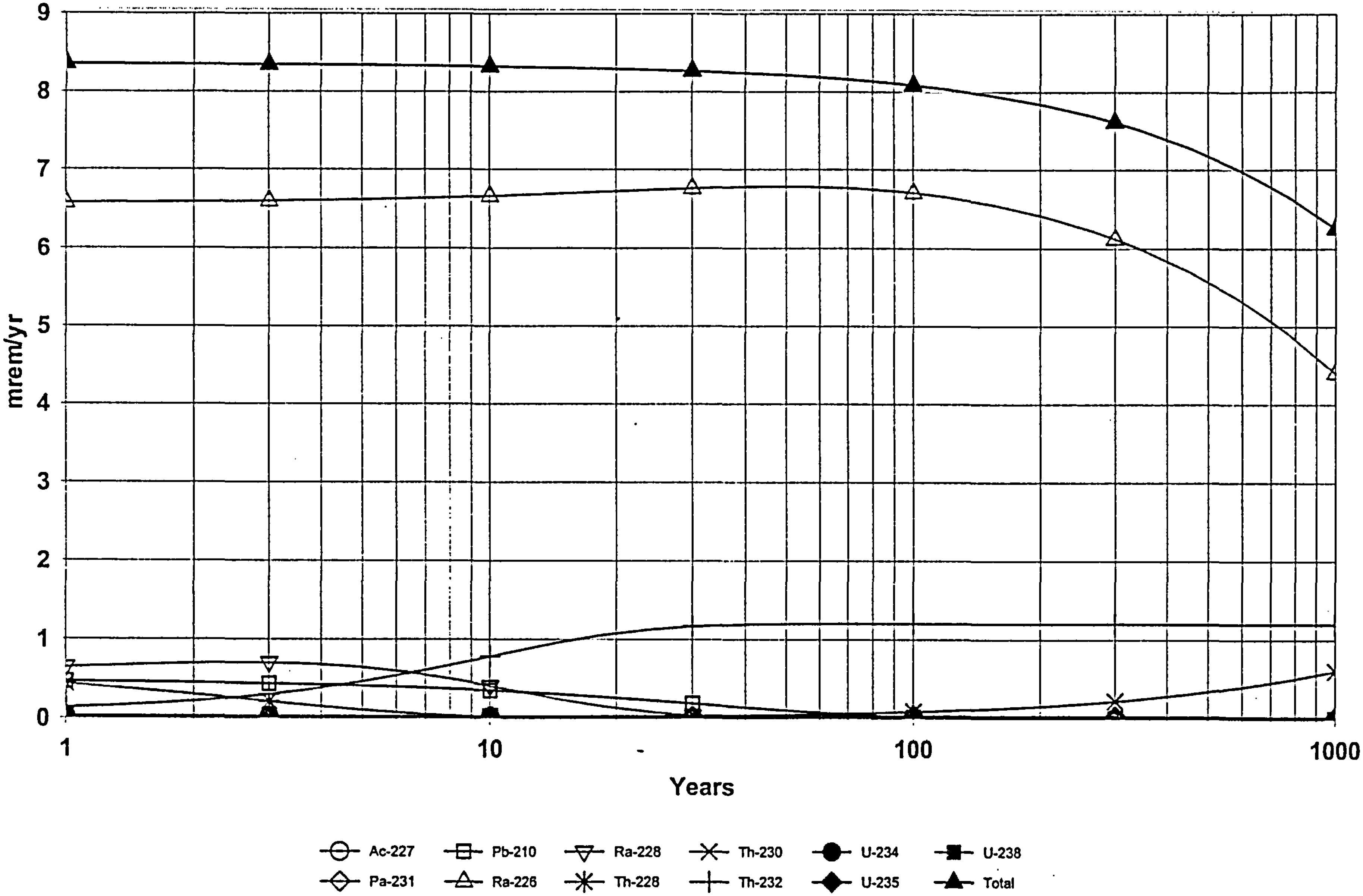
Figure 158A. 2 U Series + 0.0910 U^{235} Series + 4 Excess Ra^{226} + 4 Excess Pb^{210} + 1 Th Series



158guti.RAD 02/27/2005 10:48 Includes All Pathways

Fig 158

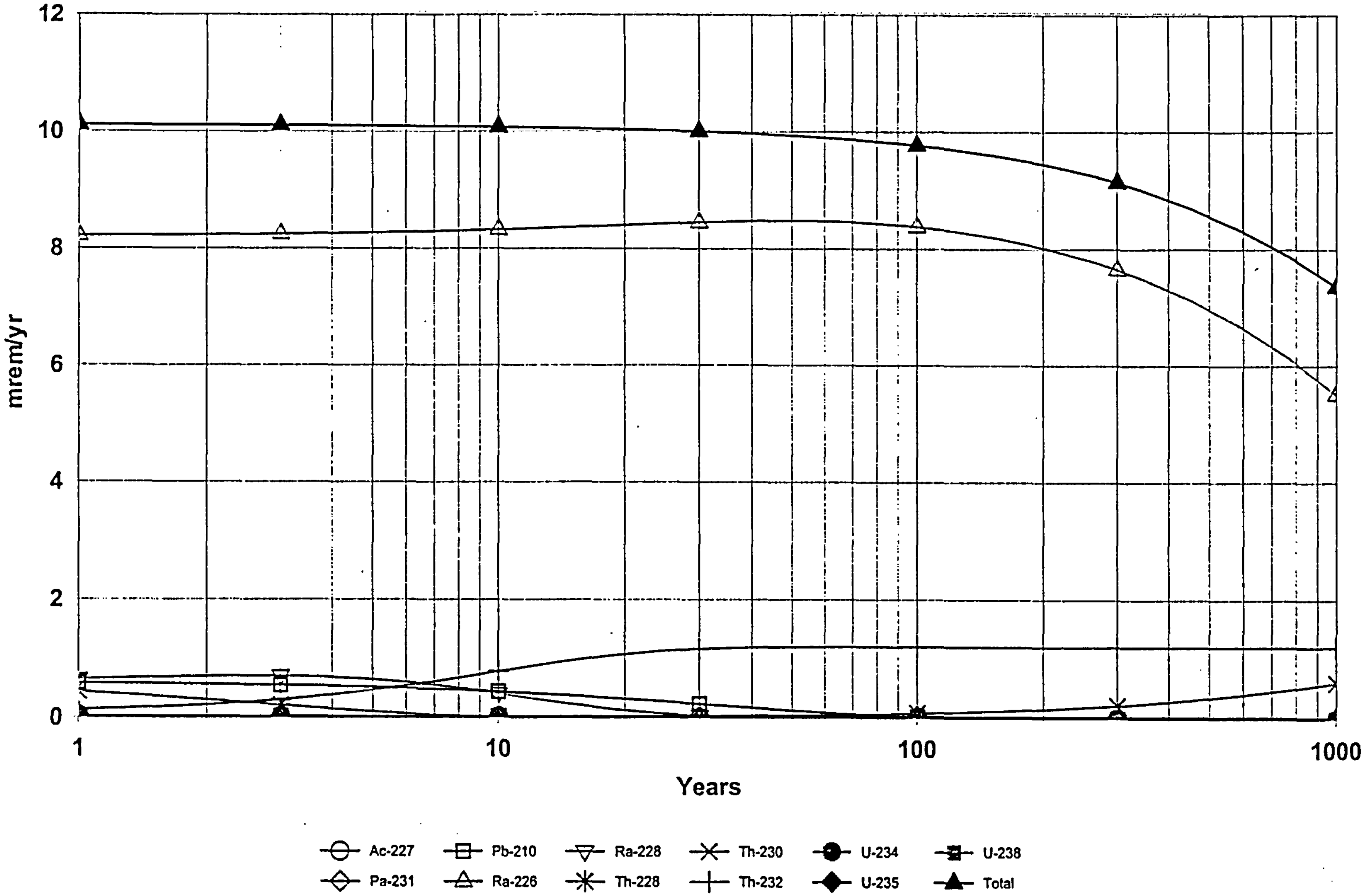
Figure 159A. 2 U Series + 0.0910 U^{235} Series + 6 Excess Ra^{226} + 6 Excess Pb^{210} + 1 Th Series



159guti.RAD 02/27/2005 10:57 Includes All Pathways

Fig 159

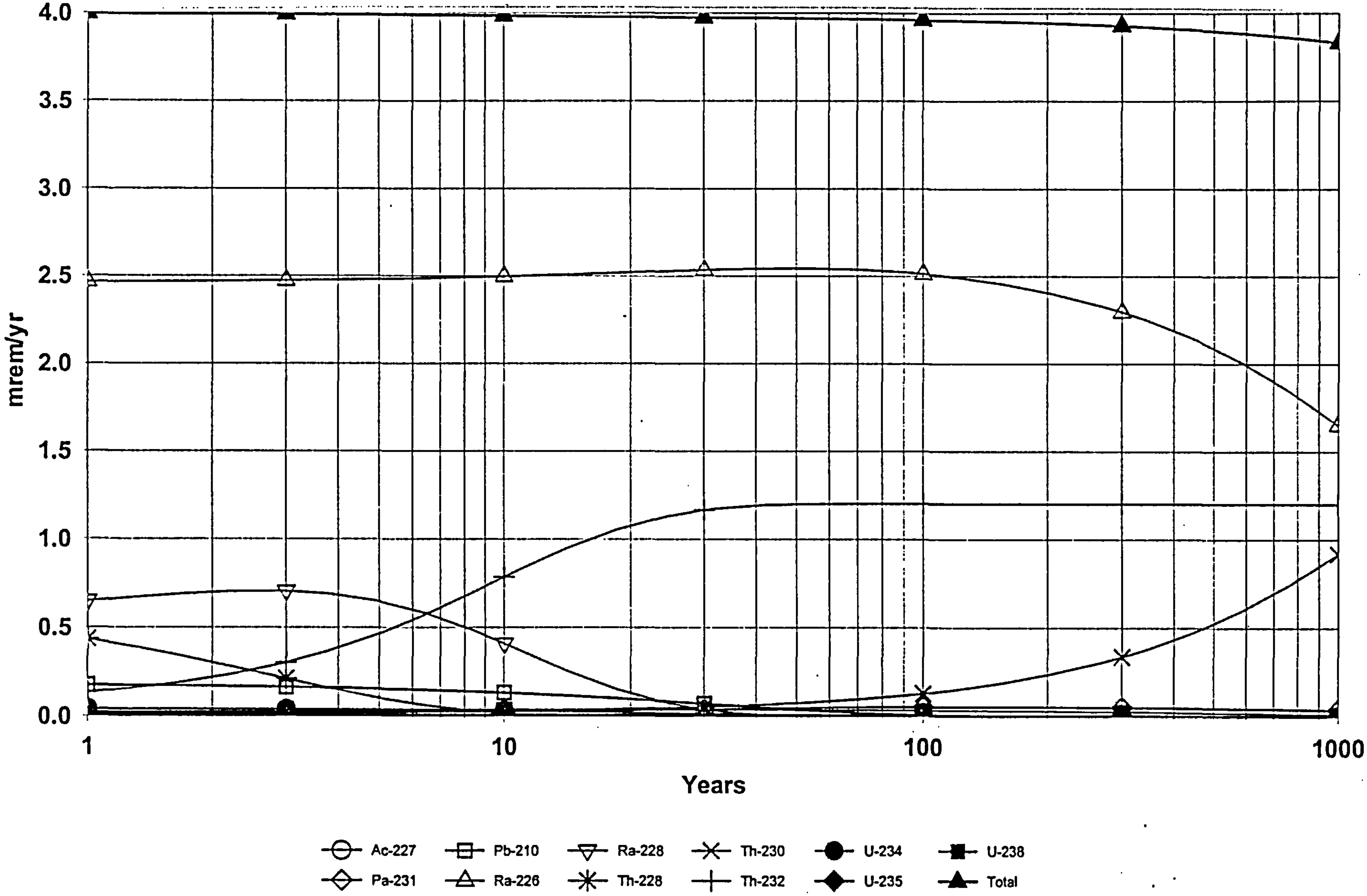
Figure 160A. 2 U Series + 0.0910 U^{235} Series + 8 Excess Ra^{226} + 8 Excess Pb^{210} + 1 Th Series



160gutl.RAD 02/27/2005 19:14 Includes All Pathways

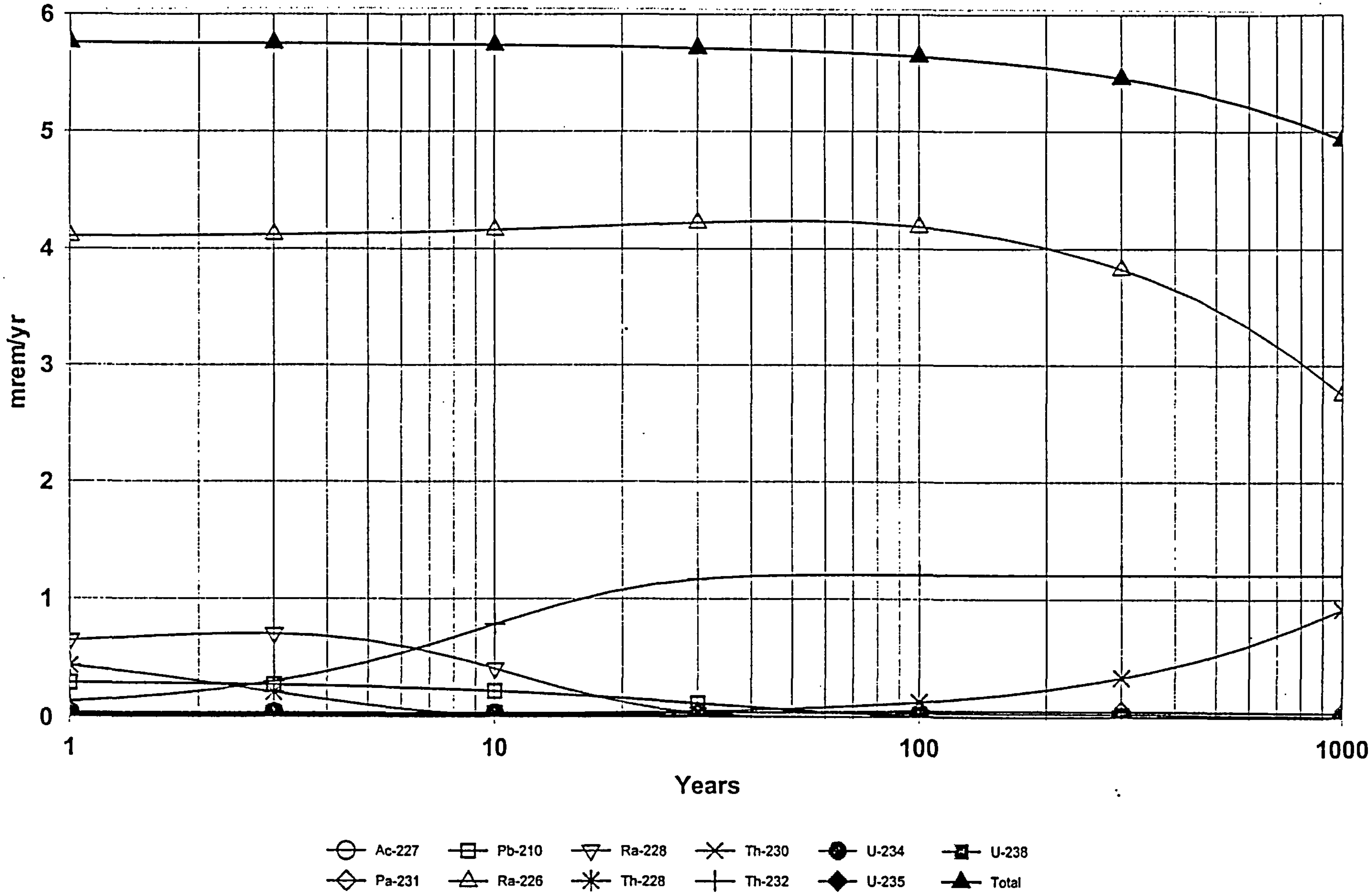
Fig 160

Figure 147A. 3 U Series + 0.1365 U^{235} Series + 1 Th Series



147gutl.RAD 02/23/2005 14:00 Includes All Pathways

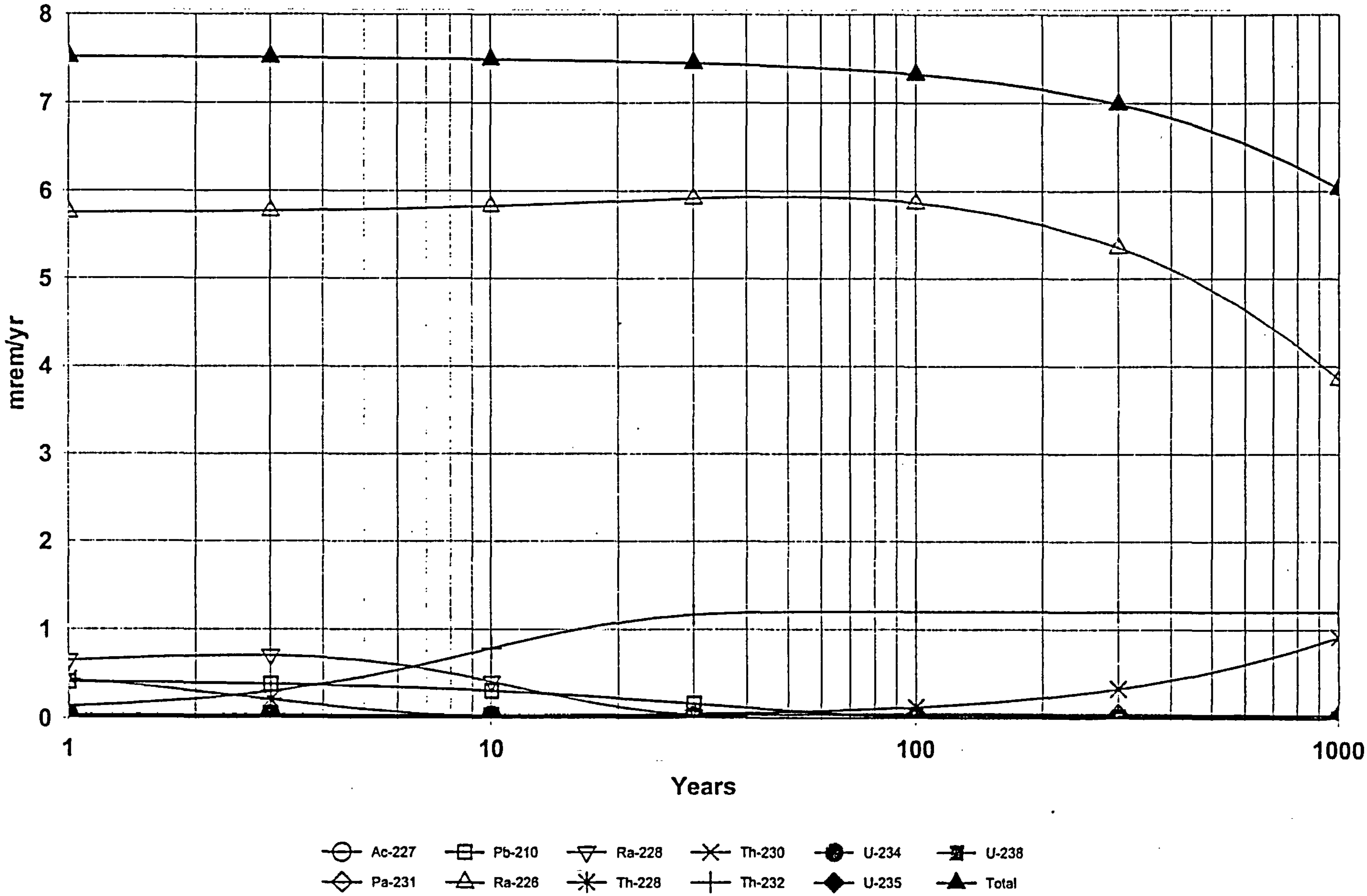
Figure 161A. 3 U Series + 0.1365 U^{235} Series + 2 Excess Ra^{226} + 2 Excess Pb^{210} + 1 Th Series



161gutl.RAD 02/27/2005 11:22 Includes All Pathways

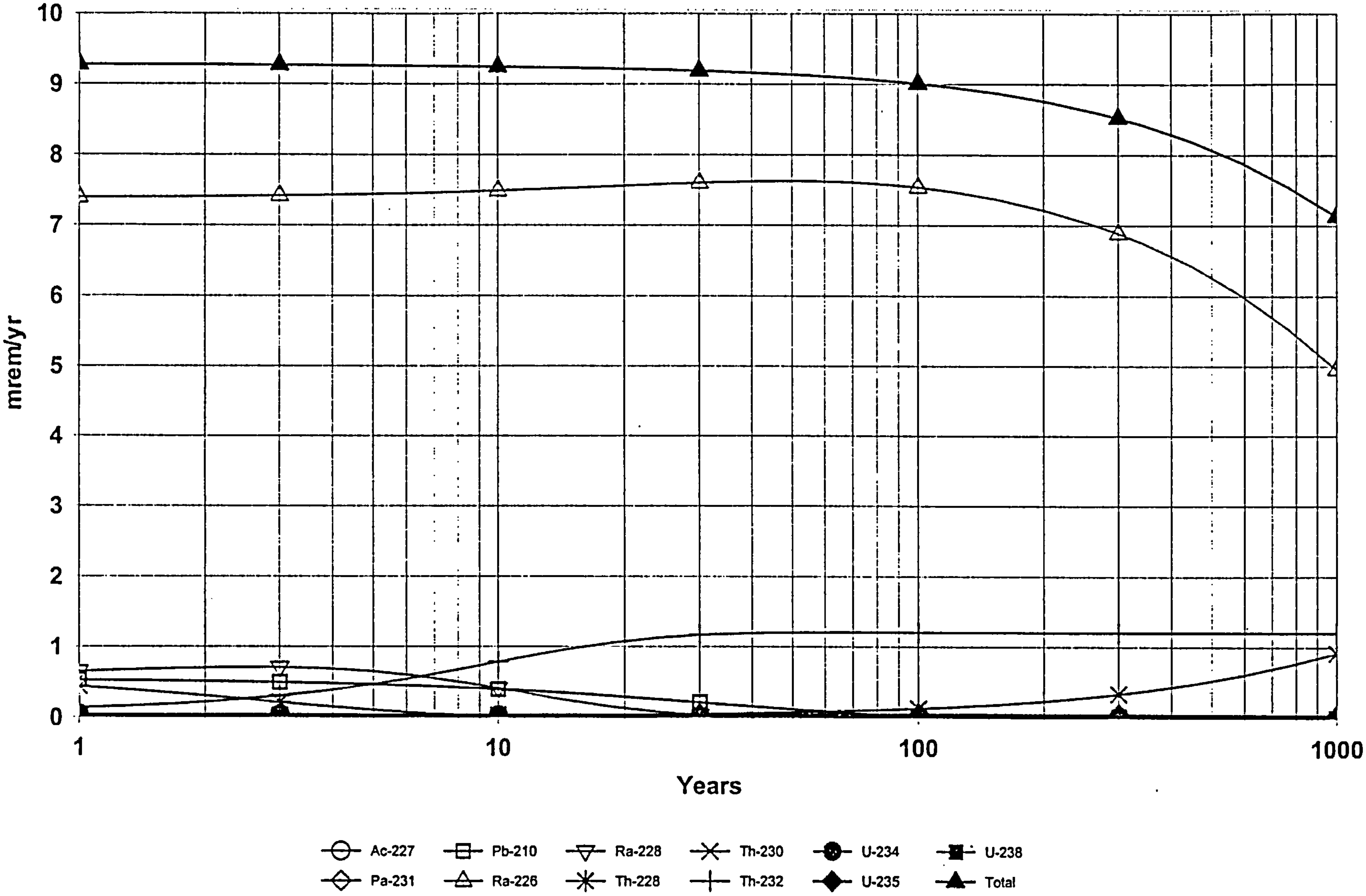
Fig 16

Figure 162A. 3 U Series + 0.1365 U^{235} Series + 4 Excess Ra^{226} + 4 Excess Pb^{210} + 1 Th Series



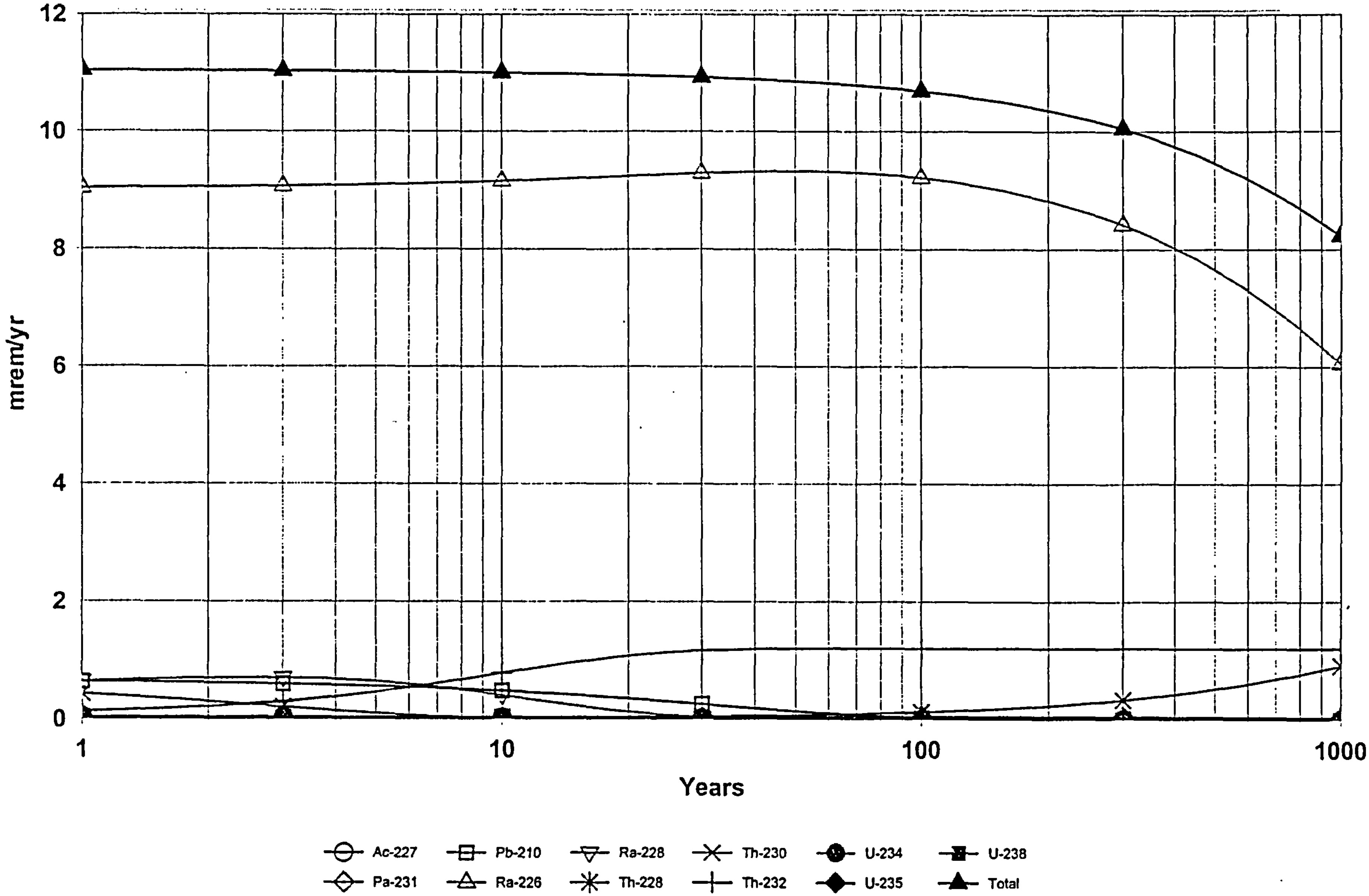
162gutl.RAD 02/27/2005 11:35 Includes All Pathways

Figure 163A. 3 U Series + 0.1365 U^{235} Series + 6 Excess Ra^{226} + 6 Excess Pb^{210} + 1 Th Series



163gutl.RAD 02/27/2005 11:49 Includes All Pathways

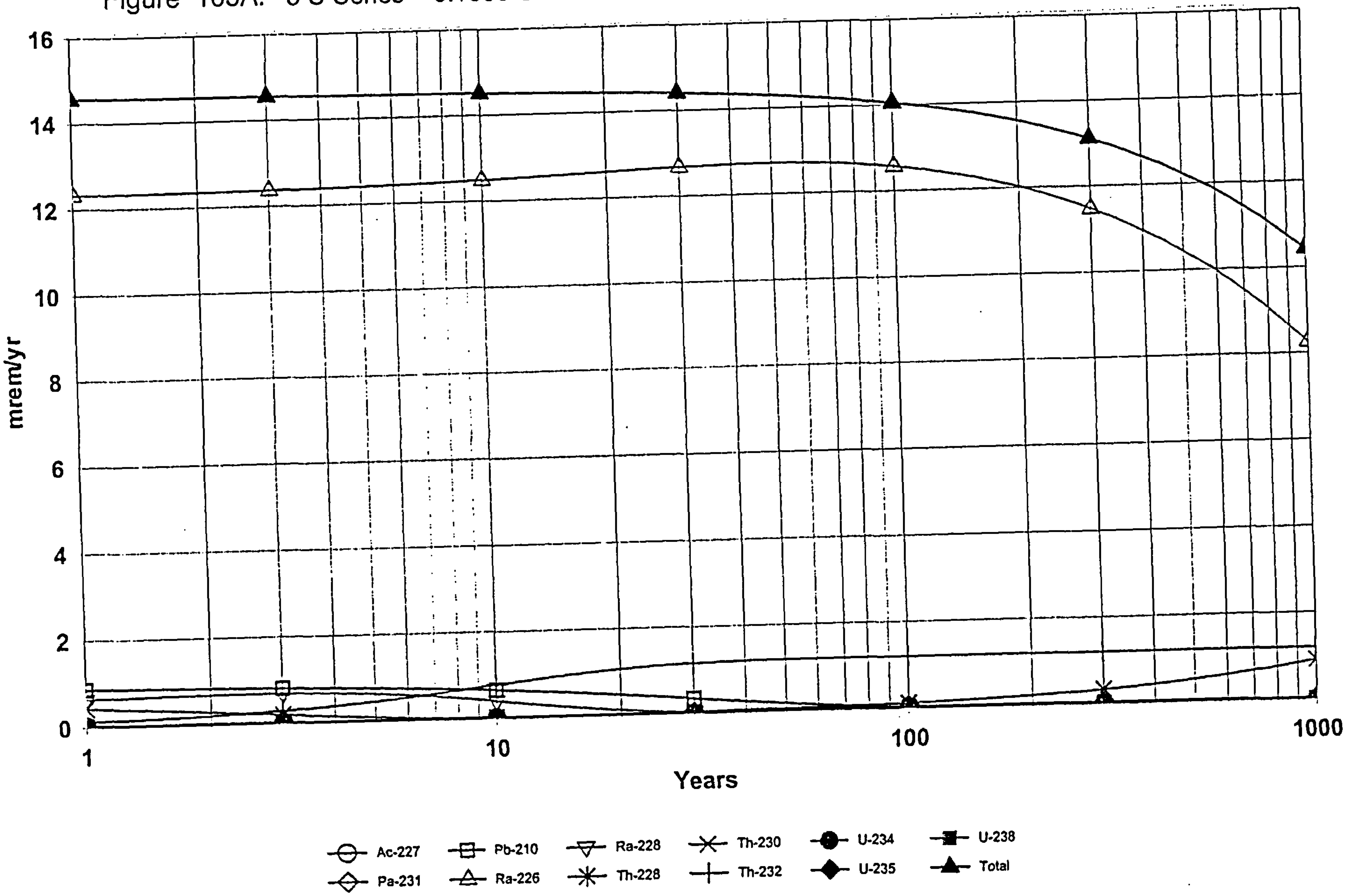
Figure 164A. 3 U Series + 0.1365 U^{235} Series + 8 Excess Ra^{226} + 8 Excess Pb^{210} + 1 Th Series



164guti.RAD 02/27/2005 11:57 Includes All Pathways

Fig 164

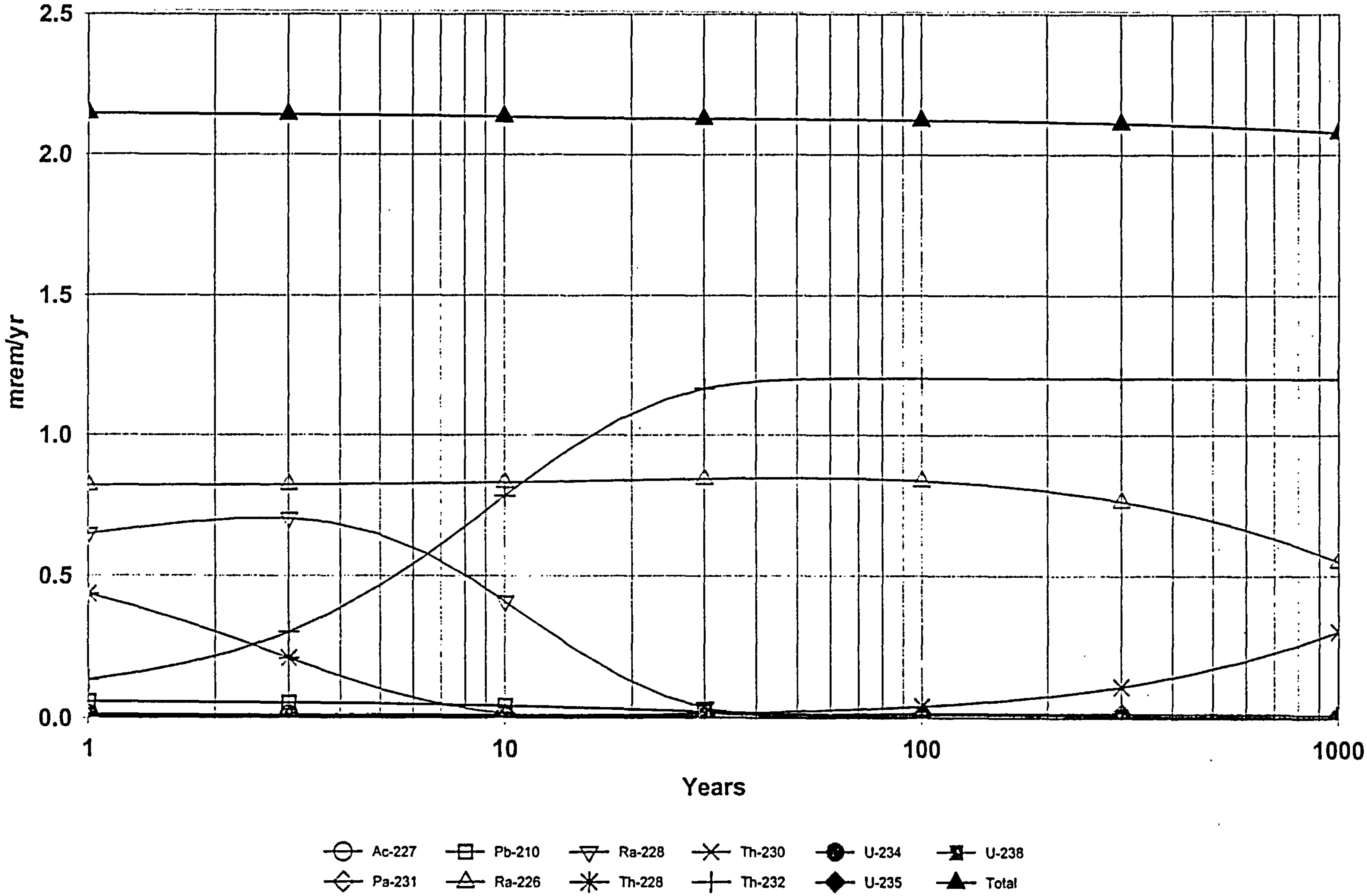
Figure 165A. 3 U Series + 0.1365 U^{235} Series + 12 Excess Ra^{226} + 12 Excess Pb^{210} + 1 Th Series



165guti.RAD 02/27/2005 12:12 Includes All Pathways

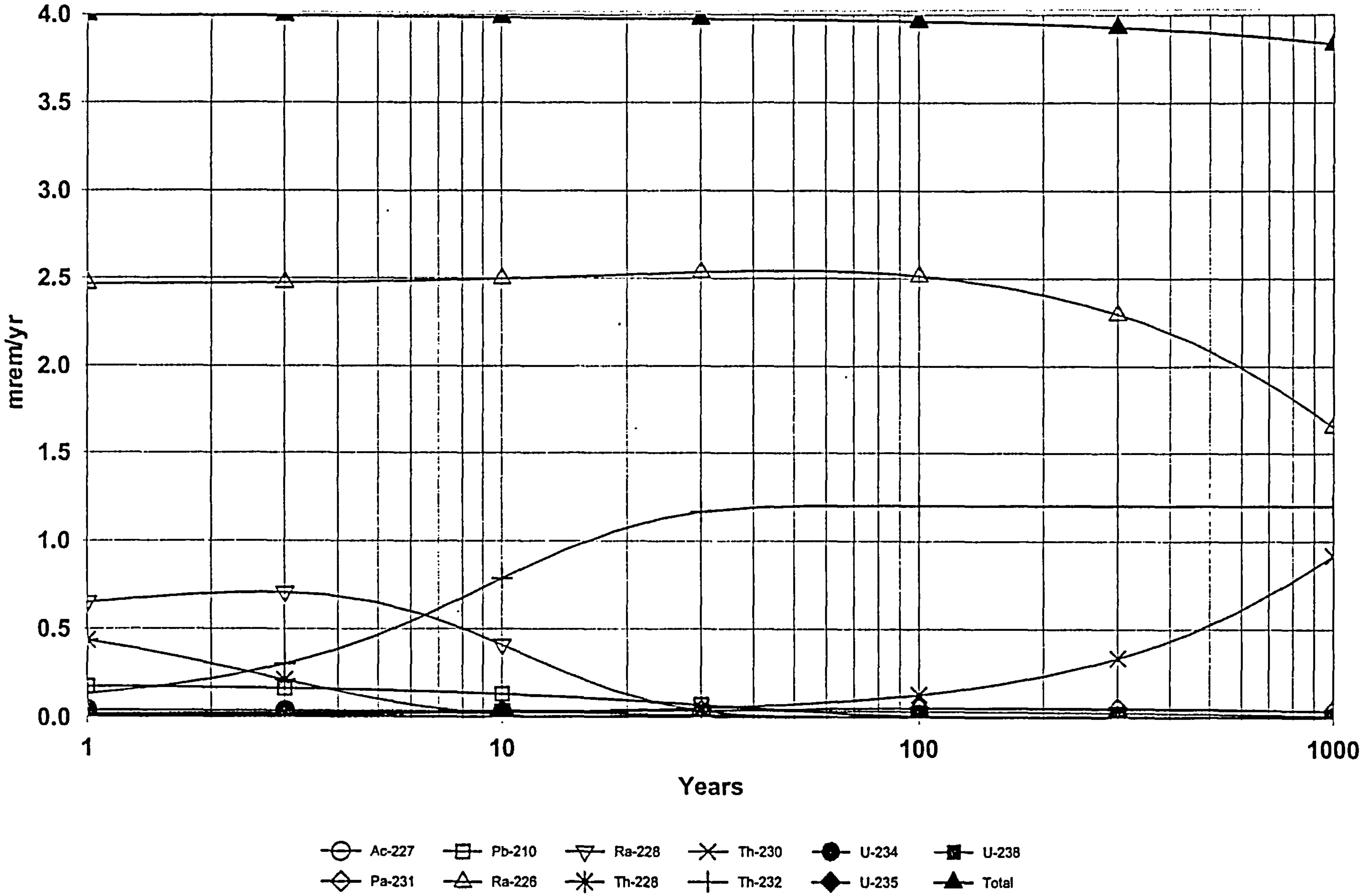
Fig '65

Figure 19A. U Series + 0.0455 U^{235} Series + 1 Th Series



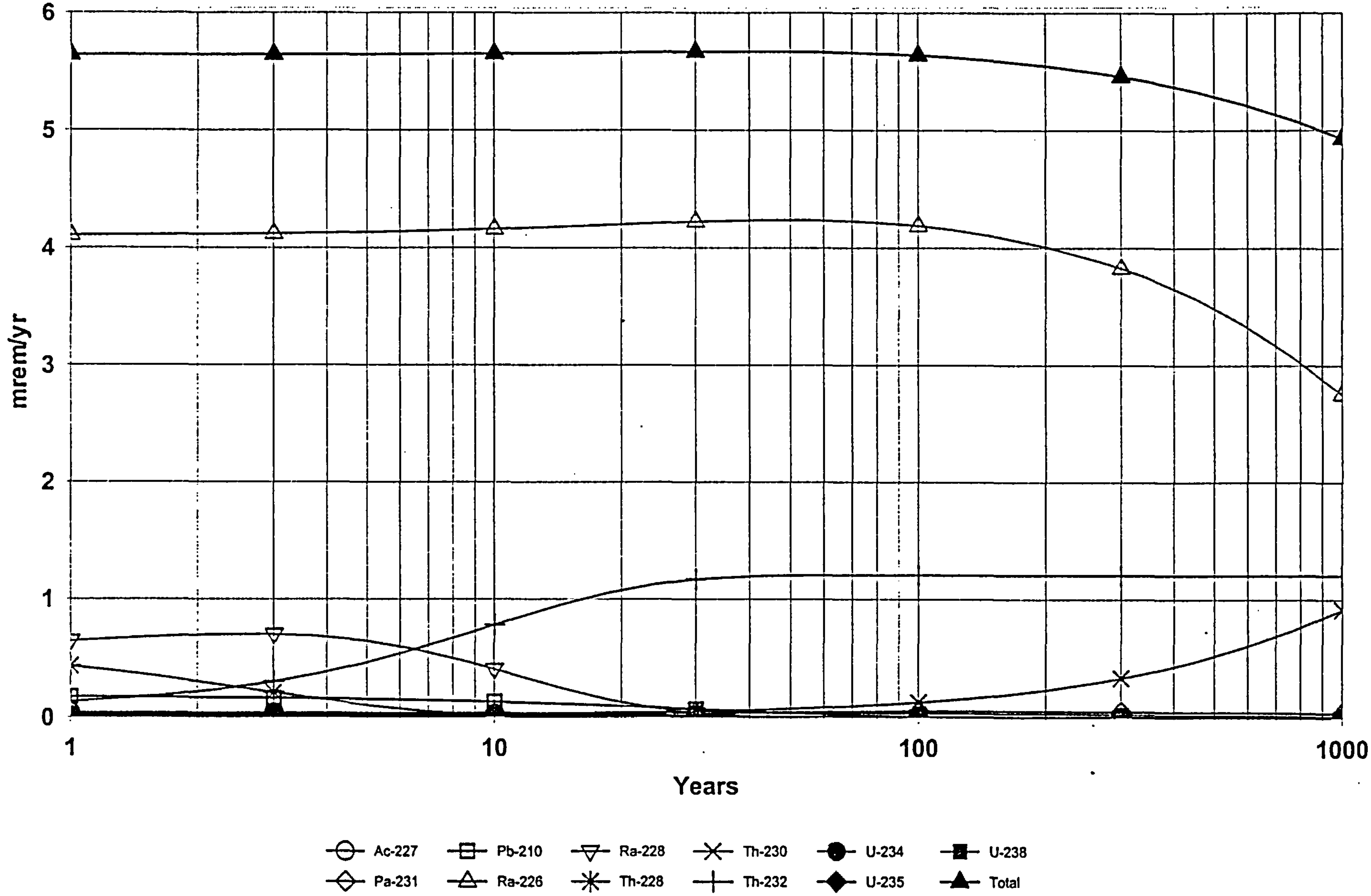
19gutl.RAD 03/03/2005 12:59 Includes All Pathways

Figure 147A. 3 U Series + 0.1365 U^{235} Series + 1 Th Series



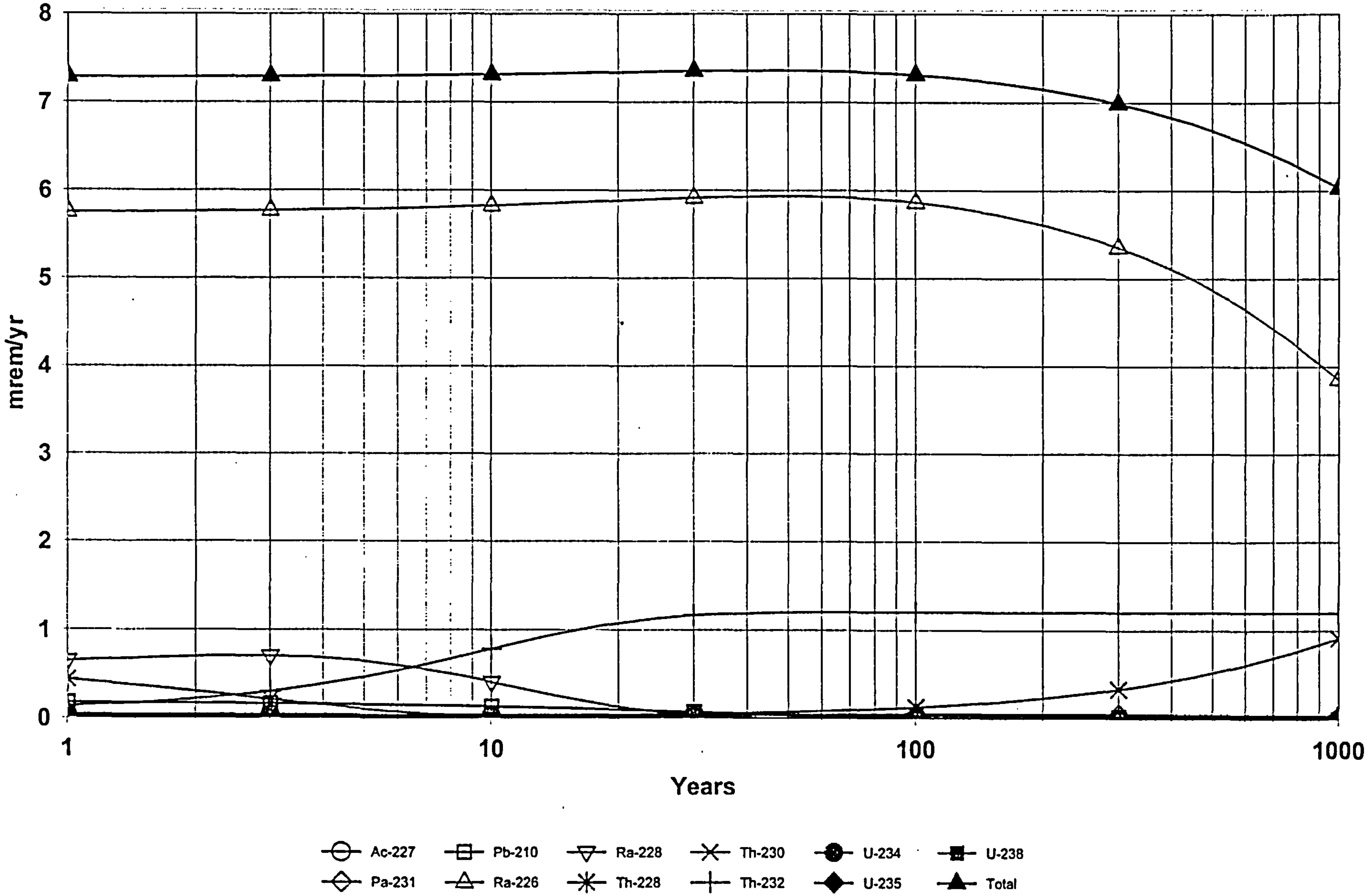
147gutl.RAD 02/23/2005 14:00 Includes All Pathways

Figure 152A. 3 U Series + 0.1365 U235 Series + 2 Excess Ra^{226} + 1 Th Series



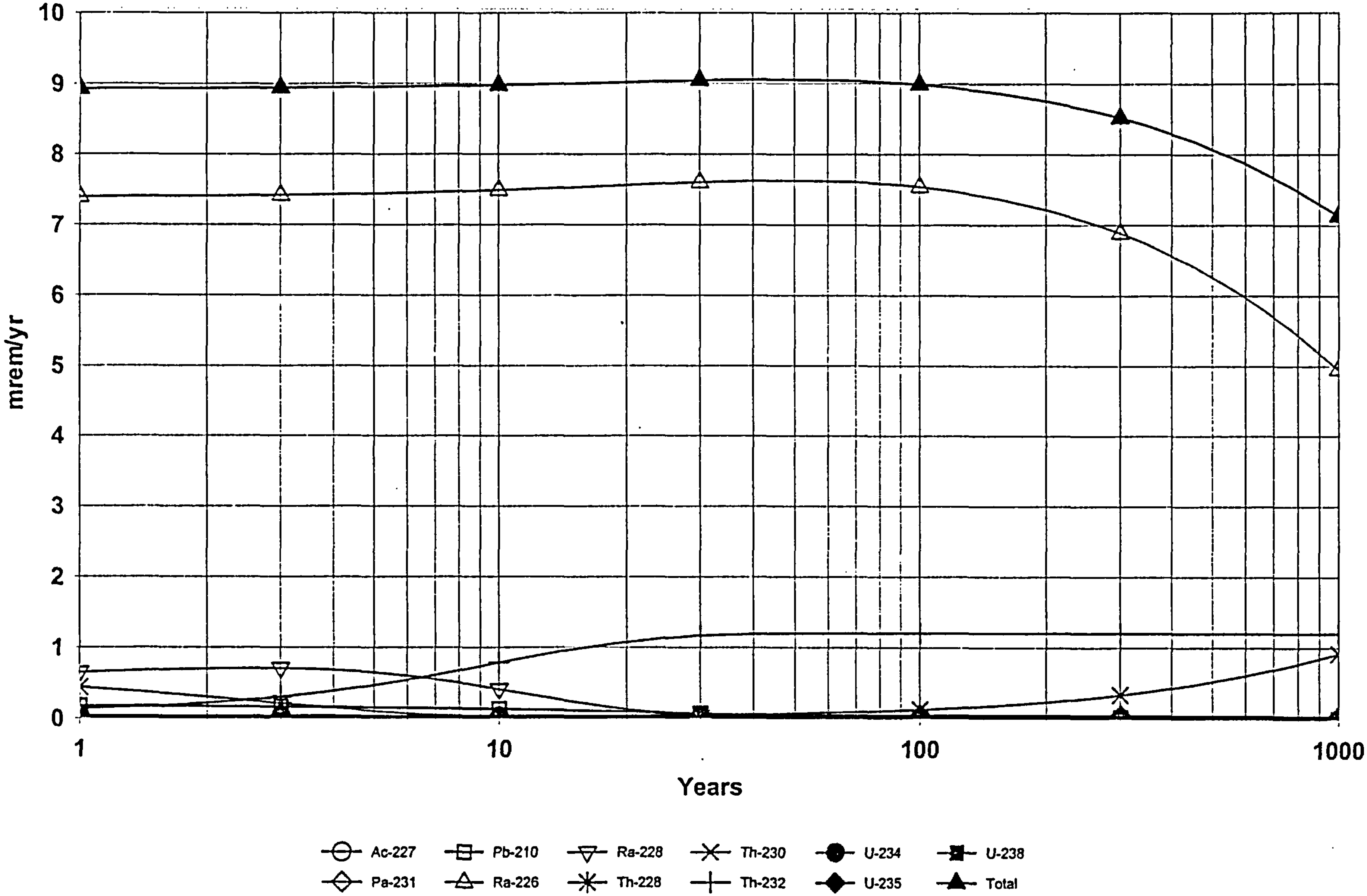
152guti.RAD 02/23/2005 15:15 Includes All Pathways

Figure 153A. 3 U Series + 0.1365 U235 Series + 4 Excess Ra^{226} + 1 Th Series



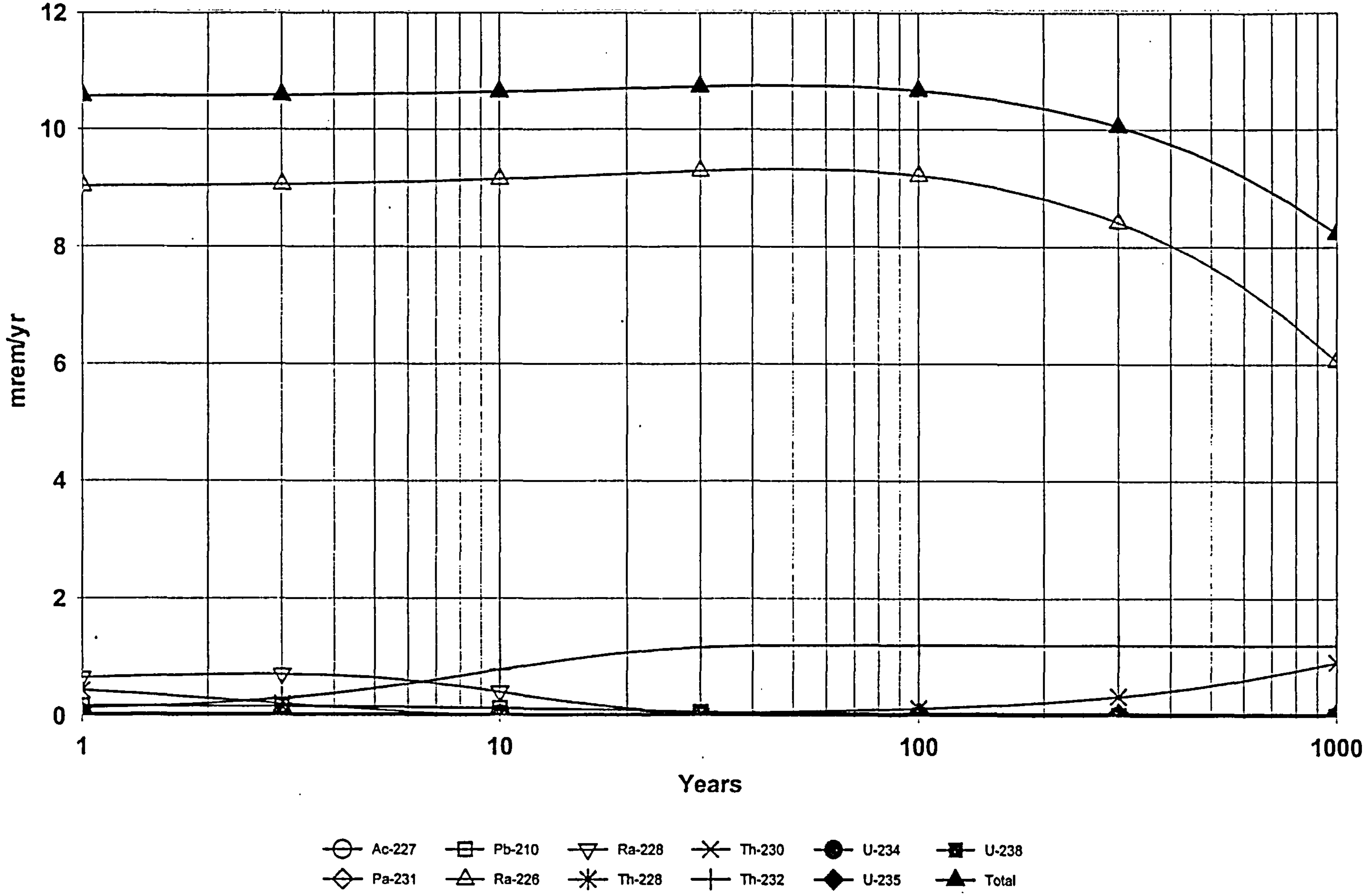
153gutl.RAD 02/23/2005 15:47 Includes All Pathways

Figure 154A. 3 U Series + 0.1365 U235 Series + 6 Excess Ra^{226} + 1 Th Series



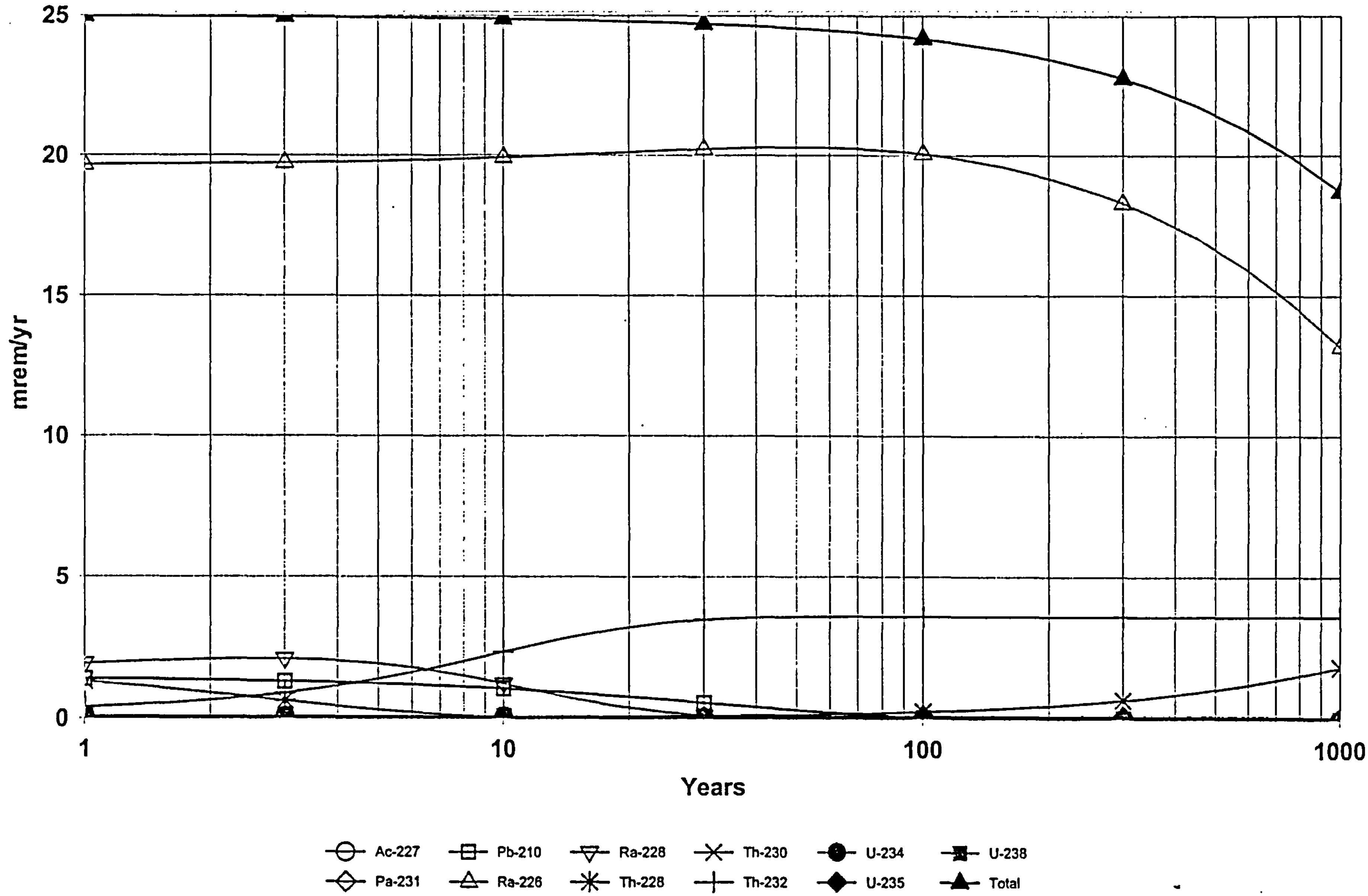
154guti.RAD 02/23/2005 15:51 Includes All Pathways

Figure 155A. 3 U Series + 0.1365 U235 Series + 8 Excess Ra^{226} + 1 Th Series



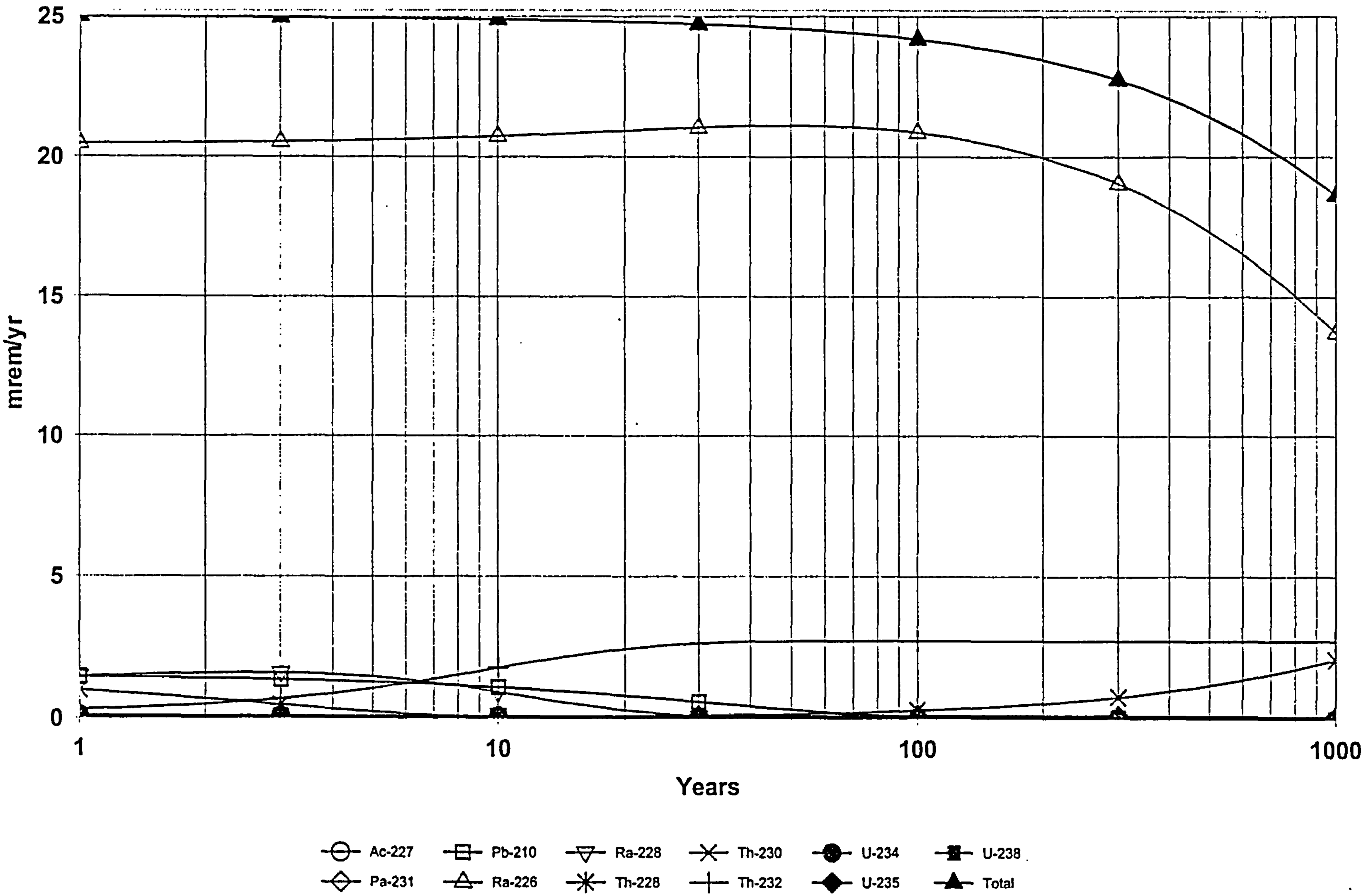
155guti.RAD 02/23/2005 15:55 Includes All Pathways

Figure 174C. RESRAD Case 174guti Verification



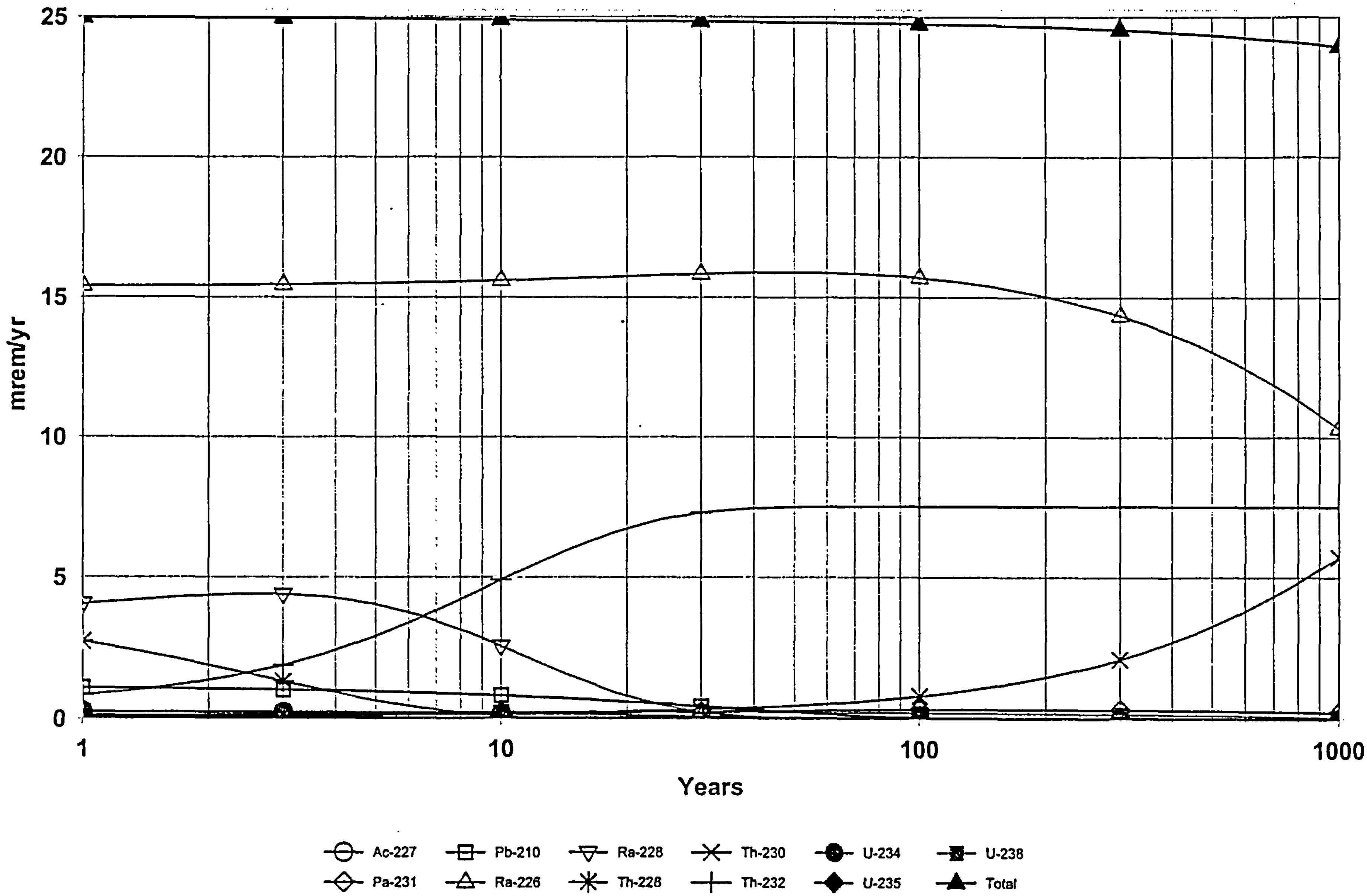
174gutl.RAD 03/03/2005 17:26 Includes All Pathways

Figure 176C. RESRAD Case 176guti Verification



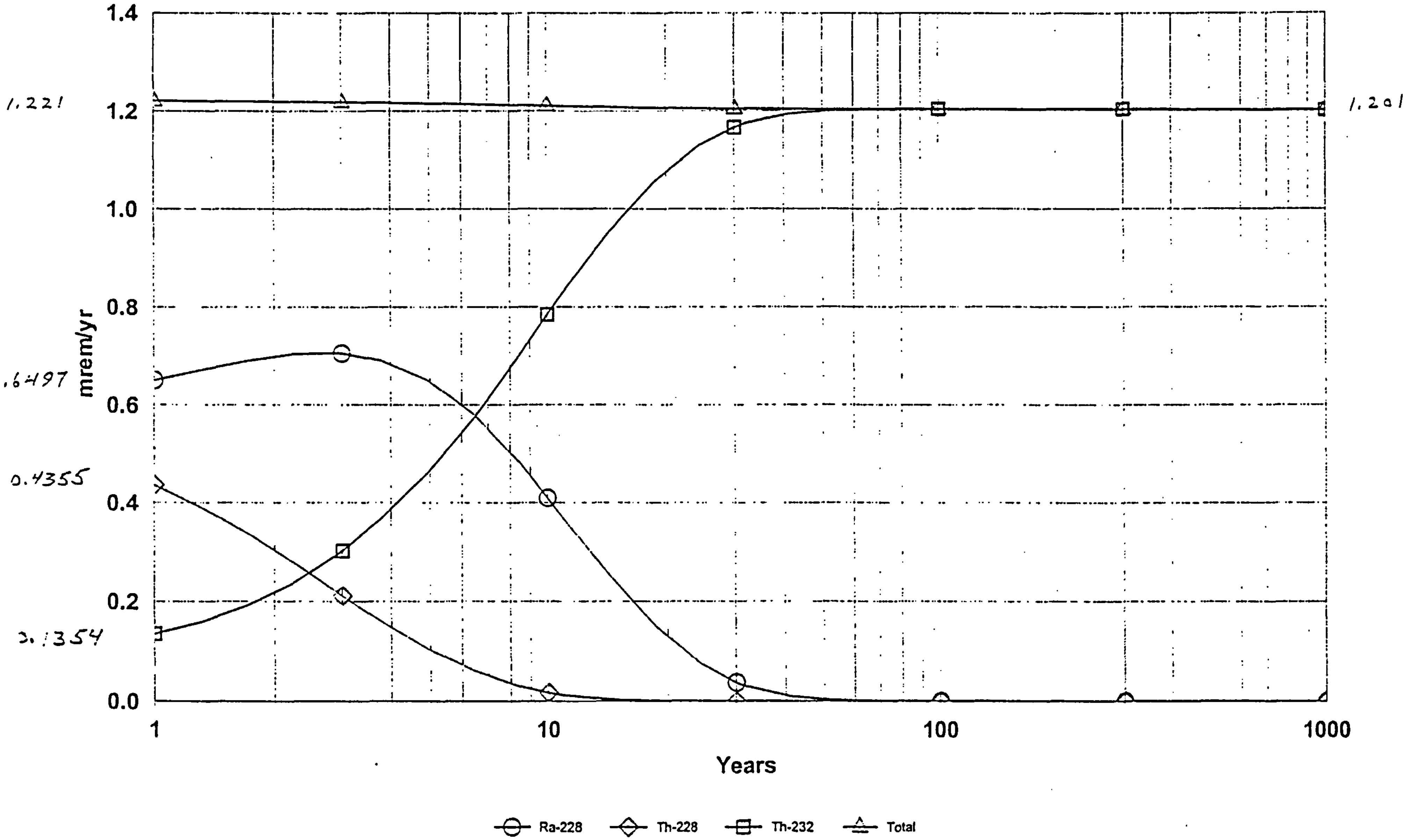
176guti.RAD 03/03/2005 18:33 Includes All Pathways

Figure 177C. RESRAD Case 177guti Verification



177gutl.RAD 03/03/2005 18:50 Includes All Pathways

Figure 168C. Th^{232}, Ra^{228}, and Th^{228} Parents and Total



168gtirae.RAD 02/28/2005 13:02 Includes All Pathways

Appendix 4144
$DCGL_W$ in Soil when Sensitive Parameters are Modeled Probabilistically

RAI Group 1
August 1, 2005

APPENDIX 4144

DCGL$_W$ IN SOIL WHEN SENSITIVE PARAMETERS ARE MODELED PROBABILISTICALLY

1. NRC REQUEST FOR ADDITIONAL INFORMATION

The NRC Environmental and Performance Assessment Directorate (EPAD) staff reviewed the derived concentration guideline levels (DCGL) applicable to soil that are described in Mallinckrodt's proposed C-T Phase II Decommissioning Plan. The staff requested additional information to clarify certain elements in the modeling of residual radioactive source-to-radiological dose essential to derivation of the proposed DCGL.[1] Most notably, the staff inquired about description of the parameters:

- residual radionuclide source as a function of depth in soil, *i.e.*, the *contaminated zone thickness*;
- density of respirable particulate in air, *i.e.*, the *mass loading for inhalation*;
- fraction of radiological dose experienced indoors as a result of gamma irradiation by residue in soil (relative to dose if the building occupied were assumed to provide no attenuation of radiation), *i.e.* the *external gamma shielding factor*;
- occupancy time indoors and, separately, out-of-doors, *i.e.*, *indoor time fraction* and *outdoor time fraction.*

Specific inquiry about these parameters is stated in the EPAD draft request for additional information, items a, b, c, and d.[2]

2. ENVIRONMENTAL SOURCE - TO - RADIOLOGICAL DOSE MODELING

In SECY-02-0177, the Staff indicated intention, among other elements, to guide site modeling in "... a cautious but reasonable approach without requiring the analyses to be overly conservative." [3] This intention was reiterated in Staff evaluation of the realistic exposure scenarios issue for the Commissioners.[4] NRC direction on this issue is summarized to allow justification of scenarios based on reasonably foreseeable land use, as opposed to defaulting to very conservative scenarios such as the resident farmer.[5] In response to Staff briefings on decommissioning during each of the past two years, including one in October 2004, an NRC Commissioner emphasized the Commission's interest in realistic scenarios for modeling.

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1 Eid, Boby. "Draft RAIs, EPAD Staff Review of Dose Assessment for Mallinckrodt C-T Phase II Decommissioning Plan, Request for Additional Information. Nov. 29, 2004.

2 also referred to in responses to NRC queries as items 41, 42, 43, and 44.

3 NRC Staff. SECY-02-0177, Issue 2.

4 NRC Staff. Results of Evaluations for Realistic Exposure Scenarios. SECY-03-0069. atch 6 & 10.

5 NRC:NMSS & NRR. NRC Regulatory Issue Summary 2004-08. Results of the License Termination Rule Analysis. May 28, 2004.

Continuation of manufacturing is the reasonably foreseeable use of Mallinckrodt's plant site in St. Louis. Industrial activity provides the appropriate scenario for the most potential for exposure to industrial workers from any C-T residue in soil. Such activity involves exposure, both out-of-doors and indoors, by direct irradiation, ingestion of soil, and inhalation of airborne dust. Estimation of potential radiological dose to industrial workers resulting from residual radioactive source in soil has been derived by mathematical simulation in models in the RESRAD computer program.

3. PARAMETERS OF INTEREST

3.1. INITIAL CONCENTRATIONS OF PRINCIPAL RADIONUCLIDES

Source materials remaining from C-T processing are the naturally-occurring uranium series, actinide (U^{235}) series, and thorium series. The principal radionuclides in those series are ones whose radioactive half-life is greater than 6 months. Progeny whose half-lives are less than 6 months are assumed to be in transient equilibrium with their longer-lived parent. Characterization survey measurements of key radionuclides in soil in Plant 5 support representation of C-T residue for the purpose of deriving DCGLw in approximately the following ratio:

- 3 uranium series,
- 0.0455 x 3 actinide series,
- 1 thorium series

This ratio is representative enough to enable RESRAD to identify the time when spectra measured during final status survey will produce maximum radiological dose, or the peak of the mean dose.

3.2. PROBABILISTIC

Parameters whose site-specific values are somewhat uncertain and to which radiological dose might be subject to significant influence by variability in value of the parameter are being treated as a distribution of values.

3.2.1. Contaminated Zone Thickness

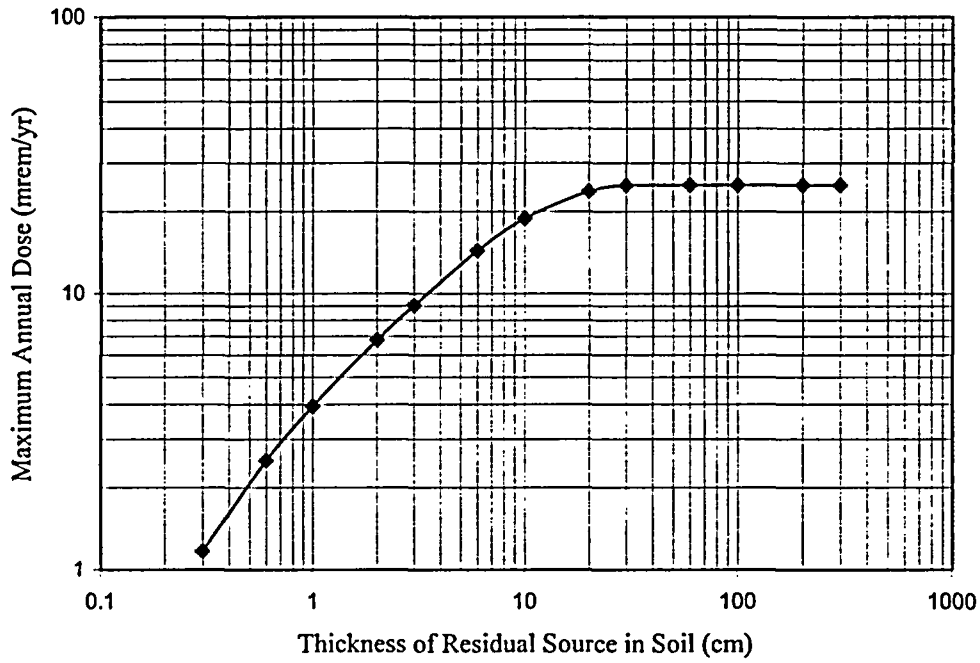
An analysis of the effect of contaminated zone thickness on radiological dose during industrial land use was done to interpret the depth beyond which additional contribution from a representative source in soil to irradiation dose to a person would become negligible. Essential features of modeling to perform this analysis were:

- a reasonably representative source ratio of 3 U series, 0.0455 x 3 actinide (U^{235}) series, and 1 Th series together.
- bare land in which residual source contamination extends from land surface downward into the soil;
- indoor time fraction = 0.0 in order to simulate effect of irradiation on bare land;
- the same industrial land use scenario modeled to derive DCGLw originally, except absent ingestion of soil and inhalation of dust; (for the origin of inadvertently ingested dust and of dust suspended into air is surficial topsoil); and

- deterministic simulation using RESRAD to derive the effect of increasing contamination depth in soil on exposure to direct irradiation.

The result of this analysis is summarized graphically in Figure 41. It determined that, in representative simulation, maximum dose rate by direct irradiation is reached asymptotically when the depth of the contaminated zone in topsoil reaches about 30 cm. Additional source thickness would not produce significantly greater dose rate.

Figure 41. Maximum Annual Radiological Dose Versus Source Depth in Soil
(infinitely-thick source ratio 3 U series + 1 Th series produces 25 mrem/yr)



As a result of this analysis, the thickness of contaminated zone parameter will be represented as a variable in probabilistic dose modeling. It is being represented as a uniform distribution ranging from 0 to 1 meter thick since characterization survey soil sampling intervals are insufficient to resolve a well-defined gradient within this range. A maximum depth of 1 meter is more than sufficient to be a conservative representation insofar as direct irradiation is concerned.

3.2.2. Mass Loading For Inhalation

The model of radionuclides in outdoor air subject to inhalation is the product of the radionuclide concentration in surface soil and the airborne density of particulates of respirable size in ambient air. Biwer, *et.al.*,[6] summarized the distribution of respirable

[6] Biwer, *et.al.* "Parameter Distributions for Use in RESRAD and RESRAD-BUILD Computer Codes." atch C, pp. C4-15 & C4-16 in NUREG/CR-6697. Dec. 2000.

particulate in ambient air reported by the EPA[7] for about 1790 air monitoring stations in a range of environments. At cumulative probability = 0.50, the most frequent respirable particulate density in the EPA distribution occurs at about 23 μg/m³ air.[8]

Three other sources of data were examined to get more comprehensive information about airborne particulate density in urban air. The total mass loading of airborne dust in an urban area has been estimated to range from 60 to 220 μg/m³ by USHEW[9] and 33 to 254 by Gilbert, *et.al.*[10] Their respective geometric means are approximately 115 and 92 μg/m³. Airborne particulates measured in 14494 urban and 3114 non-urban air samples in the National Air Sampling Network exhibited a geometric mean of 98 μg/m³.[11] A best geometric estimate of those is about 102 μg/m³.

Estimation of intake by inhalation depends on the airborne concentration of contaminated airborne particulate matter, *i.e.*, soil, that is respirable. About 0.28 to 0.33 of airborne particles have been found to be respirable, *i.e.*, less than 10 μm in diameter.[12, 13, 14, 15] The mass loading of respirable particulate in air may be estimated as the product of the total mass loading of airborne dust and the respirable fraction. Thus, a reasonable estimate of the geometric mean of respirable mass loading for inhalation in an urban, industrial area is about 0.3 x 102 μg/m³ = 31 μg/m³.

A distribution representing airborne particulate loading in urban air may be estimated by the shape of the distribution in NUREG/CR-6697, Table 4.6-1 and shifted upward by an increment representing the increase in dust in urban air relative to all ambient air. The result, in Figure 42, becomes the probabilistic distribution to replace the default distribution in RESRAD v. 6.22. This distribution represents careful, reasonable appraisal of values of airborne mass loading in an urban environment.

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7 USEPA. Aerometric Information Retrieval System. internet site http://www.epa.gov/airs/airs.html. 1999.

8 Biwer, *et.al.*, Table 4.6-1 and Fig. 4.6-1 in NUREG/CR-6697.

9 USHEW. *Air Quality Criteria for Particulate Matter.* 1969. in NUREG/CR-5512, 1, p. 6.11.

10 Gilbert, T.L., *et.al., Pathways Analysis and Radiation Dose Estimates for Radioactive Residues at Formerly Utilized MED/AEC Sites.* ORO-832 rev. Jan 1984. in Yu, C. *et.al., Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil.* ANL/EAIS-8. pp. 110-111, Apr. 1983.

11 Stern, A.C., ed. *Air Pollution.* 2nd ed. Academic Press. NY. 1968.

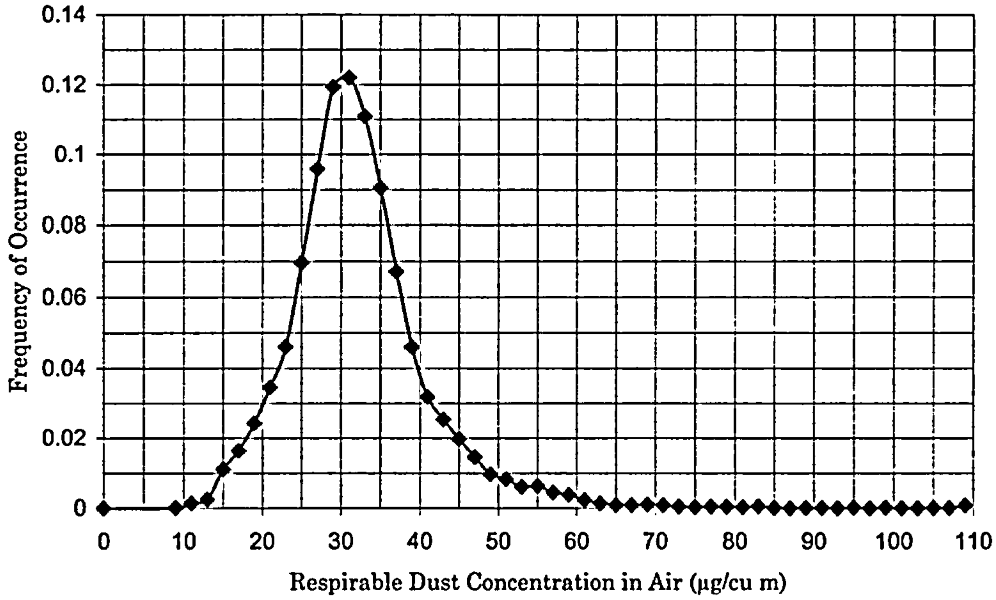
12 USEPA. *Proposed Guidance on Dose Limits for Persons Exposed to Transuranium Elements in the General Environment.* EPA 520/4-77-016. pp. 31-32. Sept. 1977.

13 Chepil, W.S., "Sedimentary Characteristics of Dust Storms: III Composition of Suspended Dust." Am. J. Sci., 225, p. 206, 1957. in EPA 520/4-77-016, p. 57

14 Sehmel, G.A., *Radioactive Particle Resuspension Research Experiments on the Hanford Reservation*, BNWL-2081, 1977.

15 Willeke, K. *et.al.*, "Size Distribution of Denver Aerosols - A Comparison of Two Sites," Atm. Env., 8, p. 609, 1974.

Figure 42. Frequency Distribution of Respirable Dust in Urban Air
(EPA AIRS PM-10 data normalized to urban environment)



It is represented in RESRAD as a continuous linear distribution with entries:

Respirable Particulate Concentration (µg/m³)	Frequency
0.	0.0
15.	0.0151
23.	0.1365
37.	0.8119
47.	0.9495
67.	0.9937
83.	0.9983
107.	0.9992

3.2.3. External Gamma Shielding Factor

An analysis of the effect of radiation attenuation by a building, especially floor thickness, on radiological dose for the portion of time a worker spends indoors during industrial occupation has been performed. Essential features of modeling to perform this analysis were:

- a reasonably representative source ratio of 3 U series, 0.0455 x 3 actinide (U^{235}) series, and 1 Th series together;

- residual source contamination extends from land surface downward one meter into the soil;
- outdoor time fraction = 0.0 in order to simulate effect of irradiation indoors;
- the same industrial land use scenario modeled to derive DCGLw originally, except absent ingestion of soil and inhalation of dust;
- deterministic simulation using RESRAD to derive the fraction of gamma dose rate as a function of concrete floor thickness [ref. Figure 43A]; and
- combination of probable distribution of floor thickesses and indoor gamma shielding factor to derive a probability distribution of indoor gamma shielding factor.
- The result of this analysis is summarized in Table 43 where indoor gamma shielding factor probability distribution is tabulated.

Table 43. Indoor Gamma Shielding Factor Distribution

Floor Thickness		Fraction of Occurrences		Indoor Gamma Shielding Factor
(inches)	(cm)	Differential	Cumulative	
2	5.08	0.01	1.00	0.38
3	7.62	0.08	0.99	0.23
4	10.16	0.26	0.91	0.142
5	12.70	0.25	0.65	0.088
6	15.24	0.18	0.40	0.055
7	17.78	0.13	0.22	0.035
8	20.32	0.08	0.09	0.0215
10	25.40	0.01	0.01	0.0084

On the premise that a floor construction is likely to be specified in an integer thickness in units of inches, a *discrete cumulative* probability distribution of these data has been specified in RESRAD. Table 43 depicts the cumulative probability and indoor gamma shielding factor data entered into RESRAD for probabilistic evaluation of the effect of this parameter on radiological dose rate.

3.3. DETERMINISTIC

Whenever potential radiological dose is relatively insensitive to uncertainty in the value of a parameter, and whenever a value that is unlikely to cause substantial underestimate of potential dose is adopted, such pertinent parameters are being described by a single-valued estimate in the current derivation of DCGL.

Default values of parameters in RESRAD v. 6 have been developed and described.[16] Unless described in the C-T Phase II Decommissioning Plan,[17] default values of parameters in RESRAD v.6 have been retained in the derivation of DCGL. The influence of parameters

[16] Biwer, B.M., *et. al.*, "Parameter Distributions for Use in RESRAD and RESRAD-BUILD Computer Codes." atch. C in *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes.* NUREG/CR-6697. Dec. 2000.

[17] C-T Phase II Decommissioning Plan, §5 Dose Modeling, §5.7 Input Parameters.

most pertinent to the scenario have been considered for appropriateness of value.[18] Deterministic values of parameters adopted and entered into RESRAD to derive DCGL appropriate for an industrial scenario are described in the C-T Phase II Decommissioning Plan, §5.[19]

3.3.1. Occupancy Fraction

Occupancy times are the fraction of a year spent indoors and the fraction of a year spent outdoors in an area on-site that was previously contaminated. Occupancy time, both indoors and out-of-doors, *i.e., indoor time fraction* and *outdoor time fraction,* directly affect potential radiological dose in industrial land use. In this case, they are the fractions of an 8766 hour year spent in an industrial scenario within an affected area of Plant 5.

In the reasonably foreseeable industrial scenario, an *industrial or commercial work* year in Plant 5 is estimated to be 50 weeks/yr x 40 hr/wk = 2000 hours/year. A worker is assumed to spend 20 percent of their time out-of-doors and 80 percent indoors. These correspond to 0.04566 of 8766 hours per year out-of-doors and 0.1825 of the time indoors. NRC staff stated that these fractions are acceptable inasmuch as they are based on an estimated 2000 working hours per year. Without a site-specific survey to refine this allocation of time, these estimates are entered into RESRAD as deterministic estimates of indoor and outdoor time fractions.

4. RESULTS OF ENVIRONMENTAL RADIOLOGICAL MODELING

4.1. DOSE FACTORS

A typical spectrum of principal radionuclides remaining from C-T has the ratio: 3 uranium series, 0.0455 x 3 actinium series, and 1 thorium series in radioactive equilibrium was entered into RESRAD in order to determine the peak of the mean radiological dose for a typical mix of these nuclides in Plant 5 soil expected after remediation. Principal radionuclide concentrations in the same ratio in soil in Table 4144A, column 2 were entered into RESRAD.

The source-to-dose modeling described in §2 herein, with values of parameters described in §3 herein, was performed with RESRAD version 6.22. Results, appended hereto, are that the peak of the mean radiological dose = 19.6 mrem/yr would occur at year 0 for a typical spectrum of residual radionuclides in soil in Plant 5 having the concentrations in Table 4144A, column 2. At no other future time was the total radiological dose any greater.

[18] ref. C-T Phase II Decommissioning Plan, §5.8.4.

[19] C-T Phase II Decommissioning Plan, §5 Dose Modeling, §5.7 Input Parameters.

Table 4144A. Probabilistic Derivation of Dose Factors Applicable to Topsoil in Plant 5

Radionuclide	Concentration in Soil (pCi/g)	Dose at Yr 0 Probabilistic (mrem/yr)	Dose Factor Probabilistic (mrem/yr) /(pCi/g)
Ac-227	0.8529	2.21E-01	2.59E-01
Pa-231	0.8529	8.80E-02	1.03E-01
Pb-210	18.75	1.04E+00	5.55E-02
Ra-226	18.75	1.19E+01	6.35E-01
Ra-228	6.248	2.58E+00	4.13E-01
Th-228	6.248	3.00E+00	4.80E-01
Th-230	18.75	1.14E-01	6.08E-03
Th-232	6.248	3.32E-01	5.31E-02
U-234	18.75	5.37E-02	2.86E-03
U-235	0.8529	3.96E-02	4.64E-02
U-238	18.75	2.11E-01	1.13E-02
All		1.96E+01	

RESRAD case 243guti

The quotient of the probabilistic mean dose of each radionuclide at the peak of the mean of the spectrum (Table 4144A, column 3) and the concentration in soil initially (Table 4144A, column 2) derives a probabilistic dose factor (Table 4144A, column 4), in units (mrem/yr)/(pCi/g), applicable for each constituent.

Origin as ore and time elapsed since processing are underlying influences toward a uranium-to-thorium series ratio and radioactive equilibrium, with some prospect of some key radionuclides in excess radioactivity. These underlying influences offer reasonable assurance that derivation of the peak of the mean dose posed by the spectrum of radionuclides modeled and typical of what is expected after remediation is the relevant basis of dose factors and DCGLw.

4.2. DCGLw

Derived Concentration Guideline Levels for the component principal radionuclides and for their composite U series, Ac (U^{235}) series, and Th series may be derived as the quotient of 25 mrem/yr and the probabilistic dose factors in Table 4144A, column 4. Resulting DCGLw are in Table 4144B. It will replace originally proposed C-T Phase II Decommissioning Plan, Table 5-1.

These DCGLw are appropriate for the residual U, Ac, and Th series in soil consequent to C-T operations in Plant 5. They would be most clearly applicable by estimating the U, Ac, and Th series in radioactive equilibrium plus the excess of any other key radionuclide that could contribute substantial additional dose. Characterization survey data indicate that only Ra^{226} would deserve to be considered prospectively in excess and a substantial contributor of additional dose.

Table 4144B. Radionuclide Limits in Soil for Industrial Scenario (CT 2 DP Table 5-1 revised)

Radionuclide	Dose Factor mrem/yr per pCi/g	DCGLw[d] pCi/g
U-238	1.13 e-2	1.944e+3
U-235 +DI[c]	4.08 e-1	5.225e+1
U-234	2.86 e-3	7.830e+3
Th-230	6.08 e-3	3.662e+3
Ra-226	6.35 e-1	3.047e+1
Pb-210	5.55 e-2	4.154e+2
Th-232	5.31 e-2	3.949e+2
Ra-228	4.13 e-1	4.692e+1
Th-228	4.80 e-1	3.996e+1
U-238 +DI[b]	7.29 e-1	3.43 e+1
Th-232 +DI[a]	9.46 e-1	2.64 e+1

[a] Th-232 +DI is the limit for Th-232 in the situation in which all progeny nuclides are present in equilibrium concentration (*i.e.*, concentration of each equal to the Th-232 concentration). Because Th-232 progeny grows in to equilibrium within about 30 years, and because the C-T facilities have existed for nearly that long, Th-232 progeny can be expected to be near equilibrium.

[b] U-238 +DI is the limit for U-238 in the situation in which all progeny nuclides are present in equilibrium and the U^{235} series is present in equilibrium as in natural uranium.

[c] Radioactivity ratio of U^{235} -to- U^{238} = 0.0455 in natural uranium.

[d] per pCi parent nuclide/g soil

DI = radioactive progeny included and assumed in radioactive equilibrium with parent