Draft

Review of NIOSH's White Paper:
Internal Exposures to Thorium and its Progeny at the Kansas City Plant during Mg-Th Machining

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ABBREVIATIONS AND ACRONYMS

Advisory Board	Advisory Board on Radiation and Worker Health
AMAD	Activity Median Aerodynamic Diameter
Bq/mL	becquerel per milliliter
Bq/y	becquerel per year
BZ	breathing zone
cm^2	square centimeter
DCF	dose conversion factor
dpm/m^3	disintegrations per minute per cubic meter
DU	depleted uranium
ER	Evaluation Report
ET	extrathoracic
h/y	hours per year
ICRP	International Commission on Radiological Protection
KCP	Kansas City Plant
m^3/h	cubic meter per hour
Mg-Th	Magnesium-Thorium
mL/h	milliliter per hour
μCi/ml	microcuries per milliliter
m/s	meter per second
NEA	Negative Exposure Assessment
NIOSH	National Institute for Occupational Safety and Health
ORAUT	Oak Ridge Associated Universities Team
rem	Roentgen equivalent man
SC&A	S. Cohen and Associates (SC&A, Inc.)
SEC	Special Exposure Cohort
SRDB	site research database
Sv	Sievert
TBD	technical basis document

1.0 EXECUTIVE SUMMARY

In its Evaluation Report (ER) for the Kansas City Plant (KCP) Special Exposure Cohort (SEC) (NIOSH 2014), the National Institute for Occupational Safety and Health (NIOSH) proposes to use air concentration limits to bound internal exposures associated with Mg-Th operations at KCP from May 1, 1957, through April 30, 1979. Item 13 of the SEC Issues Matrix (SC&A 2015) provides a status summary of discussions via the Advisory Board on Radiation and Worker Health's (Advisory Board) KCP Work Group regarding the feasibility of bounding workers' internal doses due to exposure to Mg-Th alloy operations in this manner. SC&A evaluated the assumptions used in the KCP ER in its August 2014 white paper, *Review of Internal Exposures to Thorium and Its Progeny at the Kansas City Plant during Mg-Th Machining Operations* (SC&A 2014). In that paper, SC&A concluded that NIOSH's approach to reconstructing internal doses associated with the machining of Mg-Th alloy at the KCP is based on assumptions that need to be clarified.

In particular:

1. SC&A asked for clarifications related to the thorium limit of 9E-11 μCi/ml in the period of 1957–1959. In addition, SC&A questioned NIOSH about available data to enable a determination of whether this limit was enforced and actual air concentrations of Th-232 remained generally below this limit.
2. For the 1958–1970 period, SC&A questioned NIOSH on the use of depleted uranium (DU) air concentration data for Department 20-D/Department 22 to prove that thorium limits were enforced, without evidence that any of these air samples were related to Mg-Th processing.
3. For the period after 1959, SC&A asked for clarification on whether the limit of 3E-11 μCi/ml included Th-228 and possibly other decay products of Th-232.
4. SC&A observed that NIOSH has not provided any air monitoring data for 1971–1979.
5. SC&A questioned the use of a thorium machining air concentration test done in 1970, for the entire 1970–1979 period. SC&A pointed out that this test is inadequate to determine the value that should be used, even for the year of the test, much less for any other year.
6. SC&A asked NIOSH to address the issue of doses from the progeny of thorium.
7. SC&A questioned NIOSH on the various alloy compositions that were machined.

As an action item from the June 10, 2014, meeting, NIOSH developed *Response Paper, Internal Exposures to Thorium and its Progeny at the Kansas City Plant during Mg-Th Machining* (NIOSH 2015a), addressing each one of SC&A's issues in its August 2014 paper, summarized above. SC&A reviewed NIOSH's Response Paper and at the January 20, 2015, Work Group meeting, discussed it and noted that a number of assumptions remained to be clarified. At the same time, SC&A indicated that it was satisfied that items 6 and 7 (above) had been adequately addressed by NIOSH and were recommended to the Work Group for closure consideration.[1] At the Work Group meeting, SC&A was tasked to provide this formal response to the Work Group and NIOSH.

Based on the Work Group discussions, further document review, and the March 2–5, 2015, onsite visit to KCP, SC&A has concluded the following regarding the proposed dose reconstruction approach for Mg-Th internal exposures at KCP.

1. SC&A agrees with NIOSH's recently revised information that KCP's Mg-Th machining was performed offsite by subcontractors from May 1, 1957, until August 1961, and not at the KCP site itself. According to NIOSH, Mg-Th machining operations at KCP actually began on August 23, 1961.
2. For the period, August 1961–March 1963, SC&A agrees with the NIOSH-proposed methodology to bound doses with the application of the thorium limit of 3E-11 µCi/ml. It is clear that there are gross alpha monitoring data for the location in question (Department 22), and Mg-Th and DU operations were co-located.
3. For the period 1963–1966, information remains lacking regarding the Mg-Th machining workload that was ongoing in concert with co-located DU operations. NIOSH is using DU air sampling results to show that thorium workers were not exposed to concentrations above the bounding limit of 3E-11 µCi/ml. In this context, it is important to know if DU machining was done at the same time or in the same location of Mg-Th machining, using the same machines, in order to apply DU air sampling results, as gross alpha results, containing both uranium activities and/or thorium activities.
4. For the period 1966–1970, information remains lacking regarding the location, specific timeframe, and workload for Mg-Th machining during this period. Department 20D (former Department 22),[2] where the DU machining took place until 1966 [3/3/15 KCP worker interview – SRDB pending], started to be decontaminated in that year and was likely not used (in whole or part) for Mg-Th machining. This is problematic given that NIOSH makes use of DU area air samples and surface smears for Department20D to show that the limit of 3E-11 µCi/ml was achieved in the Mg-Th machining operations, without knowing whether those operations had been relocated relative to these monitors. No further information has been found in recent data captures to resolve this issue.
5. Beyond the 1970 breathing zone (BZ) test sampling conducted in D-851, there are no air sampling data applicable to Mg-Th machining in the Model Shop, where Mg-Th machining operations took place in 1970–1979. The Model Shop had heretofore not been a designated radiological area and NIOSH's presumption regarding the rigor of radiological controls at that location during that time period is without objective basis.

[1] The issue of doses from the progeny of thorium (item 6) was acknowledged as a TBD issue; the most claimant-favorable Th-228/Th-232 proportion (0.19-triple separation or 0.5-equilibrium) for each cancer organ should be used. In terms of alloy compositions, NIOSH has provided information on the various alloy compositions that were machined.

[2] In October 1st, 1965, Department 22 changed its name to Department 20D (SRDB 123895, pages 154, 156). Department 20D is sometimes referred to as Department 20-D, D/20D, Department 20 or D/20, depending on the document.

6. SC&A finds that the proposed limiting air concentration of 3E-11 µCi/ml for Mg-Th operations at KCP is conservative and likely claimant favorable, equating to a calculated 20-year committed equivalent dose to the bone surface of 1.35 Sv (136 rem) and a 50-year bone surface committed equivalent dose of 3 Sv (300 rem), for each year of work by a Mg-Th worker, for inhalation of Type M Th-232, Th-228 and Ra-224, at thorium-228 to thorium-232 activity ratio of 0.19. The corresponding Type S committed equivalent doses to extrathoracic (ET) airways would be about 30 rem.

In summary, SC&A concludes that critical information regarding Mg-Th machining location, workload, and timeframes are lacking for 1963–1970. This information is needed to apply available DU gross alpha monitoring data to corroborate that potential thorium air concentrations are bounded by the proposed air concentration limit of 3E-11 µCi/ml. SC&A further concludes that the lone set of 1970 BZ samples taken in D-851 are inadequate to demonstrate that the 3E-11 µCi/ml limit was bounding for the Model Shop for 1970–1971. The limit, itself, is found to be conservative and likely claimant favorable, although operational information and air sampling data are lacking to corroborate that it is bounding for all relevant time periods from 1963–1979.

SC&A recommends that in the absence of such measurement data, NIOSH should validate its proposed 3E-11 µCi/ml air concentration limit through source term-based exposure modelling, followed by suitable sample dose reconstructions to demonstrate the feasibility of applying this limit for the various operational time periods in question (i.e., 1963–1966, 1966–1970, 1970–1979).

2.0 SC&A'S FINDINGS

The basic strategy adopted by NIOSH in the SEC Petition Evaluation Report for estimating the airborne dust loading of thorium and associated internal exposures during the Mg-Th operations is to use a combination of process knowledge and limits established and enforced on the maximum allowable airborne concentration of thorium. SC&A has reviewed NIOSH's Response paper, the source documents cited in NIOSH's Response Paper, and other NIOSH-provided documents available on the SRDB, in order to assess the degree to which the protocols adopted by NIOSH for reconstructing internal exposures to thorium are scientifically sound and claimant favorable.

Finding 1. Start of Mg-Th machining operations at KCP: SC&A agrees with NIOSH's recently revised information that KCP's Mg-Th machining was performed offsite by subcontractors from May 1, 1957, until August 1961, and not at the KCP site itself. According to NIOSH, Mg-Th machining operations at KCP actually began on August 23, 1961.

Finding 2. Bounding limit of 3E-11 uCi/ml: SC&A agrees with NIOSH's response to item #3 of its White Paper on the application of a bounding value of 3E-11 µCi/ml for thorium exposures in the machining work for the periods of time and locations where this limit was enforced. The application of this limit depends on NIOSH being able to corroborate for relevant operational time periods and locations that this limit was bounding of air concentrations to which Th-Mg machining workers were exposed. This has been done for 1961–1963, but is not clear for 1964–1966, and is not corroborated for 1967–1979. Page 8 of the NIOSH responses to SC&A (NIOSH

2015a), first paragraph, cites documents that describe the location and health physics procedures for 1961–March 1963. As NIOSH describes on the same page 8, after March 1963, there is no other KCP documentation of Mg-Th machining at KCP.

Finding 3. Uncertainty of Time, Workload, and Location of Mg-Th and of Uranium Machining Operations: SC&A finds that contradictory information is provided in the documented basis for defining the timeframe, operational workload, and location of radiological operations at KCP from 1961–1970.

On page 8 of the NIOSH Response, it is written:

> *After March 1963, <u>there is no other KCP documentation of Mg-Th machining at KCP or elsewhere until August 28, 1970</u>, when these operation were performed in Department 20 and the Model Shop for the Radec program* (SRDB 108264, PDF p. 26). *<u>This 1963–1970 time period with no Mg-Th machining is the same period that DU machining operations **were ramping up in Department 20**</u>.* (Emphasis added.)

In NIOSH's response to item 17 of the KCP SEC Issues Matrix for the January 20th Work Group meeting (NIOSH 2015a), it is written:

> *<u>In 1966, as DU machining work was winding down in D/20 (the only orders left were for rings and seal plugs), plans were made to transition to a new project machining polyurethane foam, and to clean D/20 and make it into an open area (123895, p. 132). The Facilities group cleaned, and the Industrial Hygiene group surveyed D/20D and D/217-20D</u>.*
>
> *Instructions were provided that stated, "…wet wipe all the walls and ceiling and other areas as the entire area walls and ceiling will be repainted, floors stripped and resealed, and equipment requiring decontamination decontaminated. Some of the equipment will go to Department 34C and can be packaged and transported to Department 34C. Some of the equipment will have to be disposed…" (123895, p. 133). Areas were surveyed for alpha contamination, and the nature of the contamination was described as follows: "Contamination is commingled with dust and is easily removed, either with soap and water or by vacuuming. Contamination levels are generally near the "open area" limit with the 'exception of bus ducts and ventilator-diffuser openings" (123895, pp. 141). In 1967, there was a request for improved housekeeping in D/34C (123895, pp. 80, 87)."*

On the other hand, Document SRDB 108264, page 8, defines Department 20D as a controlled radiation area.

Document SRDB 128373, cited as a reference to air sample results obtained in various departments, reports that during a certain period of 1966, no samples were taken in 34C, as no machining was done in this area during this sampling period. It is necessary to define where

Uranium and Mg-Th machining operations were done for each period of time and the respective workloads.

Finding 4. Adequacy and completeness of air sampling data for corroborating that 3E-11 µCi/ml limit was met for Mg-Th operations, 1961–1970: SC&A found that most of the references cited in NIOSH's response paper providing air sampling data to corroborate that the thorium limit was met are either not valid or relevant for their intended purpose, due to lack of specified time period, wrong time period (not falling within 1961–1979), or wrong or unclear plant location (not Department 20D/22 in 1961–1969, or the Model Shop, Department 851/823, during 1970–1979).

On page 10 and 11 of NIOSH's response paper, several documents containing air samples results for uranium are cited (SRDB 137071, SRDB 128390, SRDB 128206, SRDB 128240, SRDB 128373, SRDB 128377, SRDB 14700, SRDB 128344, and SRDB 128295). Those documents are provided to support NIOSH's conclusion that air sampling was in reality gross alpha and can be used to bound thorium exposures:

> *Mg-Th machining operations began in Department 20 (AKA Department 22, Heavy Machining Area) August 23, 1961 and were only performed in this department until September 21, 1970, when they were moved to the Model Shop (described previously in this report). This means the bulk of the available air-monitoring data was obtained in the department where Mg-Th machining occurred, and at the same time (SRDB 137071, PDF p.4). Although these fixed-filter air-monitoring stations were established primarily for KCP's principal machining activities (DU), they would have been analyzed for gross alpha and can be used to bound thorium exposures.* (NIOSH 2015a)

A review was performed by SC&A of the cited documents in NIOSH's response paper that serve to corroborate that the 3E-11 µCi/ml thorium limit was met. SC&A's review of each referenced set of monitoring data is summarized below (emphasis added).

a. Document SRDB 137071, page 4, is a trip report with an illegible date. It specifies the radiological safety of Departments 22, 34 and 81L. The document relates a previous survey made in September 1959. Accompanying this report is a trip report dated February 3, 1961, which falls before the starting date of the Mg-Th operations (August 23, 1961), rendering it irrelevant. <u>It is necessary to find out if the first cited trip report document was written after the start of Mg-Th operations in order for it to be a valid reference</u>.

b. Document SRDB 128390 provides air sampling results for December 1969 to December 1970, as taken in Departments 20D, 27C, 862L, and 34C. However, after September 1970, Mg-Th machining operations took place in the Model Shop (Department 851, later renamed Department 823). <u>It needs to be clearly shown that Mg-Th machining operations took place in Departments 20D, 27C, 826L or 34C from December 1969 to September 1970 for these air sample results to be relevant</u>.

c. Document SRDB 128206 contains air sample results from 1971, taken in Departments 34C, 862L, 20D, and 34C. This document is not relevant for Mg-Th machining operations, as it does not cover samples taken in the Model Shop (Department 851, later renamed Department 823).

d. Document SRDB 128240 is a 1990 document. It is not relevant for the period being analyzed.

e. Document SRDB 128373 contains air samples results taken in 1962, 1963, and 1964 in Departments 22, 34C and 216-22, and air sample results taken in 1965,1966, 1967, 1968, and 1969 in Departments 20-D, 34-C, 217-22, 217-20 (last one with the remark non-radioactive area).

   In NIOSH's response to item 17 of the KCP SEC Issues Matrix for the January 20 WG meeting (NIOSH 2015b), it is written:

   > *In 1966, as DU machining work was winding down in D/20 (the only orders left were for rings and seal plugs), plans were made to transition to a new project machining polyurethane foam, and to clean D/20 and make it into an open area* (SRDB 123895, p. 132). *The Facilities group cleaned, and the Industrial Hygiene group surveyed D/20D and D/217-20D.*

   In addition, on page 8 of the NIOSH response paper (NIOSH 2015a), it is stated that:

   > *…after March 1963, there is no other KCP documentation of Mg-Th machining at KCP or elsewhere until August 28, 1970, when these operations were performed in Department 20 and the Model Shop for the Radec program.*

   In SRDB 128373, it is reported that no samples were taken in 34C during the periods from August 23, 1966–September 8, 1966; September 9–18, 1966; October 3–17, 1967; October 18–November 1, 1966; and November 28–December 12, 1967, as no machining was done in this area during these sampling periods. The reported cleaning of Department 20 D by 1966 requires knowledge of location, time period, and workload of DU and Mg-Th machining operations during the 1963–1969 period. In summary, SRDB 128373 is a relevant document for 1962 and 1963; however, for 1963–1969, it is necessary to determine the workload of Mg-Th machining and the location where those operations took place.

f. Document SRDB 128377, page 45, is described in NIOSH's report, but was found to be dated September 23, 1958, well before Mg-Th operations took place. The information on this document is complemented by document Schiltz not dated, page 4, which provides a description of the equipment that was used. Those documents cannot be used for the purpose of showing that thorium exposures from machining operations from 1961–1979 were controlled below the limit of 3E-11 µCi/ml.

g. Document SRDB 128377, page 92, describes the measurement of suspected uranium oxide contamination using an Alpha-Air Proportional Counter Model PAC-lA. <u>It is dated August 2, 1958, before Mg-Th operations took place</u>. In addition, <u>the measurement described on page 92 relates to uranium oxide contamination in the Materials Laboratory</u>. SRDB 137071, page 4, cited before, explains that uranium oxide, in a very finely divided form, was received in sealed gallon cans, which were opened in an exhaust ventilated hood or in a blending room designed for the purpose. Thus, the suspected oxide contamination was probably not related to uranium machining operations.

h. The information in this document (SRDB 128377) is complemented by document SRDB 128344, page 131, which describes the alpha-gamma scintillation counter portable model PAC-1S AGA offered by Eberline in 1960 (Eberline - National Radiation Instrument Catalog, national-radiation-instrument-catalog.com/new_page) and by document SRDB 128295, page 4, dated May 1, 1977, which describes the use of survey meter PAC-1SAGA to check leaks of several calibration sources. <u>Those documents cannot be used with the purpose of showing that thorium exposures from machining operations from 1961–1979 were controlled below the limit of 3E-11 µCi/ml</u>.

Finding 5. Adequacy of a Single Thorium Machining Air Concentration Test, Done in September–October 1970 to be used as Bounding for the Entire 1970–1979 Period. SC&A and NIOSH are in apparent agreement "that the sensitivity of this test was not high..." NIOSH further states that it "believes that the assessment KCP performed from September 18 to October 10, 1970 (prior to the second Mg-Th campaign), is useful as additional data to support the ER's bounding method, as well as KCP's good work practices." (NIOSH 2015a).

<u>SC&A disagrees that there should be reliance on practices performed in the 1971–1979 period based on a single test conducted before the bulk of Mg-Th machining operations took place, even if used as a complement to air monitoring data taken in Department 20-D</u>. Mg-Th machining operations took place in the Model Shop (Department 851), considered an uncontrolled area (SRDB 108264, page 8). Air monitoring data from two different departments in different exposures periods are not necessarily equivalents.

Finding 6. Adequacy and completeness of routine contamination surveys for corroborating that 3E-11 µCi/ml limit was met for Mg-Th operations, 1970–1979: SC&A does not agree with NIOSH in its use of KCP surface contamination data coupled with its programmatic premise that there was no indication of degradation of "in-plant environmental working conditions" as sufficiently rigorous or objective, given the total absence of any bioassay or air monitoring data.

On page 12 of NIOSH's response paper, three documents containing KCP routine surface contamination monitoring results for uranium are cited (SRDB 123883, SRDB 123889, and SRDB 123896). Those documents are intended to complement the 1970 BZ air sampling performed prior to relocation of Mg-Th operations from Department 20-D/22 to the Model Shop, albeit, the surface surveys taken do not cover the 1971–1979 period.

On page 12 of NIOSH's response paper, it is stated:

> *NIOSH has not found additional routine air-monitoring data for the time period after KCP performed the Negative Exposure Assessment (NEA) for their Model Shop Mg-Th machining operations from September 18 to October 10, 1970. (SRDB 108264, PDF p.16). In the absence of additional air-monitoring data, NIOSH has also considered data from KCP's routine surface contamination monitoring program as an indication of workplace conditions (SRDB 123883; 123889; 123896). NIOSH modeled the surface contamination that would have been created from the natural settling of air concentrations at KCP's prescribed limit and compared the result to the actual surface contamination data. NIOSH used the 3E-11 μCi/ml (66.6 dpm/m^3) airborne concentration limit and assumed a 7.5E-4 m/s settling rate (Battelle-TBD-6000) for 30 days, and derived a 1,295 dpm/100 cm^2 surface contamination level. By comparison, routine survey records show the average measured level recorded for the Department 20 general area from 1962 to 1969 to be 892 dpm/100 cm^2 (ORAUT-TKBS-0031, Table 10). There are no indications that KCP's control of work or in-plant environmental working conditions degraded in the years after the cessation of air monitoring, which leaves NIOSH confident that exposures remain bounded with the use of the 3E-11 μCi/ml limit specified in the ER.*

a. Document SRDB 123883 reports floor monitoring results in various departments in 1960, <u>before Mg-Th machining operations took place</u>. It cannot be used in the relevant time period.

b. Document SRDB 123889 reports floor monitoring results taken in various departments in 1959 and 1960, <u>before Mg-Th machining operations took place</u>. It cannot be used in the relevant time period.

c. Document SRDB 123896 reports floor monitoring results in various departments, including 20D or 22 in 1962, 1963, 1964, 1965, 1967, 1968, and 1969. The results confirm NIOSH's statement that the average measured level recorded for the Department 20/22 general area from 1962 to 1969 was less than 1,295 dpm/100 cm^2 surface contamination level. It is relevant for the period 1962–1969. <u>There are no monitoring data for the period 1971–1979, neither air or surface monitoring, when the machining of Mg-Th took place in the Model Shop</u>.

SC&A does not share NIOSH's confidence that "there are no indications that KCP's control of work or in-plant environmental working conditions degraded in the years after the cessation of air monitoring." The Model Shop (Department 851) was considered an uncontrolled area, with application of corresponding Health and Safety Guide criteria and procedures for an uncontrolled area, while Department 20-D was a controlled radiation area. This was, in fact, emphasized in a memorandum from Robert T. Foster to V.J. Smeltzer (Foster 1971) titled, "Development Support Project Using Magnesium-Thorium Alloy" (SRDB 108264, page 8). The first three sentences of the memorandum are reproduced below:

> *As you requested in your referenced correspondence, we have reviewed the health and Safety Guide dated August 28, 1970, and believe it should not be relaxed…*

Based on our past experience, it is recommended that this work be completed in Department 20-D, radiation area, instead of the Engineering Shop, Department 851... Considerable difficulty would be experienced in explaining an incident involving radioactive materials while machining and fabrication of parts on a continued temporary basis in an uncontrolled area (D/851) when a controlled area (D/20-D) has been provided for such work…

Finding 7. SC&A finds that the proposed limiting air concentration of 3E-11 µCi/ml for Mg-Th operations at KCP is conservative and claimant favorable, albeit, operational information is lacking to corroborate actual airborne concentrations of thorium during most time periods. The application of the limit translates into high 20–50 years committed equivalent doses to the bone surface, lungs and extrathoracic airways.

NIOSH has proposed to apply the engineered limit of 3E-11 µCi/ml as a constant for the period 1961–1979. NIOSH assumes that machine operators in the Main Manufacturing Building breathed air at this concentration for 2,000 hours per year.

SC&A calculated the 20-yr, 30-yr and 50-yr committed equivalent doses to various tissues and organs, which dominate committed doses,[3] as a preliminary means to validate the concentration limit, as applied. For thorium, the main systemic tissues and organs in terms of deposition and long-term retention are bone surface, liver, and red bone marrow. The lung is an important organ in terms of deposition and retention of inhaled material.

NIOSH has suggested using a 0.19 ratio for Th-228/Th232 as "a claimant-favorable assumption because the dose conversion factors are higher for thorium-232."

SC&A noted that when the cancer organ is the lung, it is claimant favorable to assume equilibrium between Th-228 and Th-232. SC&A proposed at the January 20, 2015, WG meeting, with NIOSH's agreement, that the most claimant-favorable Th-228/Th-232 ratio (0.19 assuming triple separation of thorium, or 0.5 assuming equilibrium), should be chosen for each cancer organ (NIOSH 2015b).

Considering that the standard worker breathes 1.2 m^3/h or 1.2E6 mL/h, and is exposed to 2,000 h/y, the annual intake corresponding to the limiting concentration of 3E-11 µCi/mL (1.11E-6 Bq/mL) is 2.664E3 Bq/y, which comprises the alpha activities of Th-232, Th-228, and Ra-224. For an activity ratio of 0.19 Th-228/Th-232 and Ra-224/Th-232, the intake rates corresponding to the air activity of 3E-11 µCi/mL (1.11E-6 Bq/mL) are 1,930 Bq/y of Th-232, 367 Bq/y of Th-228, and 367 Bq/y of Ra-224. Committed equivalent doses were obtained by multiplying the intake rates of 1,930 Bq/y of Th-232, 367 Bq/y of Th-228, and 367 Bq/y of Ra-224 by the committed equivalent dose coefficients in Sv/Bq taken from the ICRP Database of Dose Coefficients, version 3.0, 2011 (ICRP 2011).

Table 1 shows the 20-yr, 30-yr and 50-yr committed equivalent doses to bone surface, liver, and red bone marrow for each year of exposure to Mg-Th machining at the limiting concentration of 3E-11 µCi/mL (1.11E-6 Bq/mL), considering Type M thorium exposures.

[3] Doses to different organs correspond to 1-year exposures to the limiting concentration of 3E-11 µCi/mL.

Table 1. Committed Equivalent Doses to Various Organs and Tissues, due to 1-year Intake of 1,930 Bq of Th-232, 367 Bq of Th-228, and 367 Bq of Ra-224, considering Type M Thorium

Committed Doses (Sv) to	Type M Th-232	Type M Th-228	Type M Ra-224	Total
Bone Surface				
20 yr	1.25E+00	1.03E-01	3.49E-04	1.36E+00
30 yr	1.81E+00	1.03E-01	3.49E-04	1.92E+00
50 yr	2.9E+00	1.03E-01	3.49E-04	3.0E+00
Liver				
20 yr	2.12E-02	4.4E-03	1.1E-05	2.56E-02
30 yr	2.90E-02	4.4E-03	1.1E-05	3.34E-02
50 yr	4.44E-02	4.4E-03	1.1E-05	4.88E-02
Red Bone Marrow				
20 yr	6.37E-02	8.07E-03	3.34E-05	7.18E-02
30 yr	8.11E-02	8.07E-03	3.34E-05	8.92E-02
50 yr	1.1E-01	8.07E-03	3.34E-05	1.18E-01

Table 2 shows the 20-yr, 30-yr and 50-yr committed equivalent doses to lungs and ET Airways for each year of exposure to Mg-Th machining at the limiting concentration of 3E-11 µCi/mL (1.11E-6 Bq/mL), considering Type S thorium exposures:

Table 2. Committed Equivalent Doses to Lungs and ET Airways due to 1-year Work, considering Type S Thorium, and Intakes of 1,930 Bq of Th-232, 367 Bq of Th-228, and 367 Bq of Ra-224

Committed Equivalent Doses (Sv) to	Type S Th-232	Type S Th-228	Type M Ra-224	Total
Lungs				
20 yr	1.20E-01	7.71E-02	7.34E-03	2.04E-01
30 yr	1.35E-01	7.71E-02	7.34E-03	2.2E-01
50 yr	1.49E-01	7.71E-02	7.34E-03	2.33E-01
ET Airways				
20 yr	1.93E-01	7.71E-02	2.2E-03	2.72E-01
30 yr	2.12E-01	7.71E-02	2.2E-03	2.92E-01
50 yr	2.12E-01	7.71E-02	2.2E-03	2.92E-01

Table 3 shows the 20-yr, 30-yr and 50-yr committed equivalent doses to lungs and ET Airways for each year of exposure to Mg-Th machining at the limiting concentration of 3E-11 µCi/mL (1.11E-6 Bq/mL), considering that thorium is in equilibrium with the daughters. This corresponds to intakes of 888 Bq/y for Th-232, Th-228, and Ra-224. Committed equivalent doses were obtained by multiplying the intake rates of 888 Bq/y of Th-232, Th-228, and Ra-224 by the committed equivalent dose coefficients in Sv/Bq taken from the ICRP Database of Dose Coefficients, version 3.0, 2011 (ICRP 2011).

Table 3. Committed Equivalent Doses to the Lungs and ET Airways for Thorium in Equilibrium with Daughters, for Each Year of Work , for Types M and S Thorium

Committed Doses (Sv) to	Type M Th-232	Type M Th-228	Type M Ra-224	Total
Lungs				
20 yr	1.15E-02	1.15E-01	1.78E-02	1.45E-01
30 yr	1.24E-02	1.15E-01	1.78E-02	1.46E-01
50 yr	1.42E-02	1.15E-01	1.78E-02	1.47E-01
ET Airways				
20 yr	1.07E-02	5.15E-02	5.33E-03	6.75E-02
30 yr	1.15E-02	5.15E-02	5.33E-03	6.84E-02
50 yr	1.33E-02	5.15E-02	5.33E-03	7.02E-02
Committed Doses (Sv) to	**Type S Th-232**	**Type S Th-228**	**Type M Ra-224**	**Total**
Lungs				
20 yr	5.51E-02	1.86E-01	1.78E-02	2.59E-01
30 yr	6.22E-02	1.86E-01	1.78E-02	2.66E-01
50 yr	6.84E-02	1.86E-01	1.78E-02	2.73E-01
ET Airways				
20 yr	8.88E-02	1.86E-01	5.33E-03	2.81E-01
30 yr	9.77E-02	1.86E-01	5.33E-03	2.89E-01
50 yr	9.77E-02	1.86E-01	5.33E-03	2.89E-01

The committed equivalent doses to bone surfaces from inhalation exposures to Type M Th-232, Th-228, and Ra-224 at the limiting concentration, distributed in an equilibrium ratio of 0.19 for Th-228/Th-232 and Ra-224/Th-232, are high. For each year of work, the worker will receive a 20-year committed equivalent dose to the bone surface of 1.36 Sv (136 rem) and a 50-year committed equivalent dose of 3 Sv (300 rem). The corresponding Type S committed equivalent doses to the ET Airways are about 30 rem, while the 20-year–30-year committed equivalent doses to the lungs vary from 20–23 rem. For Type S thorium exposures, the lungs show greater committed equivalent doses when Th-232 is in equilibrium with Th-228 and Ra-224. In this case, the 20-yr–50-yr committed equivalent doses to the lungs are about 27 rem, and the 20-yr–30-yr committed equivalent doses to the ET airways are about 29 rem.

In conclusion, although there is a lack of information on airborne thorium concentrations during confirmed and suspected Mg-Th operations at KCP, the application of the limiting concentrations to the workers translates into high assigned doses to certain organs and tissues, especially bone surface. The calculated committed equivalent doses correspond only to doses from exposure to Th-232, Th-228, and Ra-224 through inhalation of 5 AMAD particles. Dose from ingestion and thoron exposures, for example, were not considered.

Remaining Questions:

Based on the foregoing results of the SC&A review, the following specific questions remain for resolution by the WG:

1. Were Mg-Th machining and DU machining done at the same time and in the same area? As already cited in Finding 4, NIOSH states :

   > *Mg-Th machining operations began in Department 20 (AKA Department 22, Heavy Machining Area) August 23, 1961 and were only performed in this department until September 21, 1970, when they were moved to the Model Shop (described previously in this report). This means the bulk of the available air-monitoring data was obtained in the department where Mg-Th machining occurred, and at the same time (SRDB 137071, PDF p.4). Although these fixed-filter air-monitoring stations were established primarily for KCP's principal machining activities (DU), they would have been analyzed for gross alpha and can be used to bound thorium exposures.*

   The document SRDB 137071 that NIOSH cites as proof that Mg-Th machining was conducted at the same time and in the same department as DU machining does not cite Mg-Th machining and does not have a legible date; thus, it is not possible to know if the trip report cited took place before August 1961, when Mg-Th machining operations started. In addition, the document states that all work with radioactive material was performed in Departments 22, 34 and 81L, but it does not specify which type of work was done in each of the departments.

   None of the documents cited by NIOSH provides any proof that Mg-Th machining operations took place at the same time and in the same location as DU machining work.

   NIOSH is using DU air-sampling results to show that thorium workers were not exposed to concentrations above the bounding limit of 3E-11 μCi/ml. In this context, it is important to know if DU machining was done at the same time and in the same location of Mg-Th machining, in order to use DU air-sampling results, as gross alpha results, containing both thorium activities and uranium activities.

2. Were air samplers positioned near Mg-Th machining, or were they placed near DU machining? It is important to know if air samplers were placed near Mg-Th machining work.

3. Were the machines assigned to non-radioactive machining in the same area as the ones used for machining radioactive materials? Did the workers use machines designated for radioactive materials when doing Mg-Th machining? Were the exhaust and ventilation systems the same in the area of non-radioactive machining and radioactive machining? What about the Health Protection standards? Did Mg-Th machining always take place in the same area of Department 20-D?

In Department 22, workers did machining of non–radioactive material as well as machining of radioactive materials, in 1964 and 1965. Document SRDB 123895 cites some concerns on the use of machines assigned for radioactive material being used for machining non-radioactive material (pages 20, 24, 155 and 166).

4. Did machining of non-radioactive materials take place at the same time as radioactive material? Did the dust from machining non-radioactive materials interfere with the quality of the air inhaled by the workers doing Mg-Th or DU machining?

5. What was the workload of Mg-Th machining in relation to the workload of DU machining in Department 20-D (formelly Department 22)? Did Mg-Th machining take place every year during the period 1961–1970? Was it done sporadically, or was it a continuous work? What about DU machining?

   If Mg-Th machining was **not** done at the same time as DU machining, than the DU air-sampling results that are reported are related only to DU machining work. It is important to know the DU workload in relation to the workload of Mg-Th machining during the period 1963–1970. If the DU workload was higher than the Mg-Th workload, then DU air samples can be used to show that potential exposures to thorium were below the bounding limits. The same applies to Mg-Th work being done at the same time, but in a different area of the same department, if air samplers were positioned with the objective of monitoring DU machining work.

6. Where did Mg-Th machining take place during the period 1966–1970? It is important to know the length of time that Department 20-D remained a clean area. NIOSH is using DU air samples in Department 20-D to show that exposures to thorium were below the bounding limit. Samples taken in a clean area are not representative of exposures to workers.

7. Which exhaust and ventilation systems existed in the Model Shop during the period 1971–1979? Which Health Protection programs existed for the workers in the Model Shop? It is important to collect whatever information exists regarding health protection of Mg-Th machining workers during the period 1971–1979.

3.0 NON-SEC ISSUES

1. Doses from the Progeny of Thorium

   In NIOSH's response to item #5 of its paper, the use of 0.19 ratio of Th-228 to Th-232 is proposed. NIOSH sustains that:

   > *It is likely that the thorium would have been triple-separated over the course of several years prior to use at KCP… Triple-separated thorium, subject to pessimistically chosen intervals between chemical purification, results in a thorium-228 to thorium-232 activity ratio of 0.19. By minimizing the ratio of*

thorium-228 to thorium-232 the assumed isotopic mixture is weighted in favor of thorium-232.

NIOSH states that the 0.19 ratio is "a claimant-favorable assumption because the dose conversion factors are higher for thorium-232." SC&A notes that the 0.19 ratio is not claimant favorable for all organs and tissues. For the lungs, for example, the DCF for Type M Th-228 is 1.3E-4 Sv/Bq, and for Type M Th-232 is 1.6 E-5. The dose to the lung per unit intake is a factor of 10 lower for Th-232, as compared to the dose from Th-228. For Type S Th-228, the DCF is 2.1E-4 and the DCF for Type S Th-232 is 7.7E-5 [ICRP Database of Dose Coefficients (ICRP 2011)]. When the cancer organ is the lung, it is claimant favorable to assume equilibrium between Th-228 and Th-232.

SC&A proposed at the January 20th WG meeting, with NIOSH's agreement, that the most claimant-favorable Th-228/Th-232 ratio (0.19 assuming triple separation of thorium, or 0.5 assuming equilibrium) should be chosen for each cancer organ. This item has been acknowledged as a TBD issue.

2. Nominal Thorium Concentration of the Mg-Th Alloys Machined at KCP.

   In its response paper, NIOSH has given adequate information on the composition of Mg-Th alloys.

4.0 CONCLUSIONS

1. SC&A agrees with NIOSH's recently revised information that KCP's Mg-Th machining was performed offsite by subcontractors from May 1, 1957, until August 1961, and not at the KCP site. According to NIOSH, Mg-Th machining operations at KCP actually began on August 23, 1961.

2. For the period August 1961–March 1963, SC&A agrees with the NIOSH-proposed methodology to bound doses with the application of the thorium limit of 3E-11 µCi/ml. It is clear that there are gross alpha monitoring data for the location (Department 22) in question, and Mg-Th and DU operations were co-located.

3. For the period 1963–1966, information remains lacking regarding the Mg-Th machining work load (i.e., was Mg-Th even being machined?) that was ongoing in concert with co-located DU operations.

4. For the period 1966–1970, information remains lacking regarding the location, specific timeframe, and workload for Mg-Th machining. Department D-20 (former D-22), where the DU machining took place until 1966 [3/3/15 KCP worker interview – SRDB pending], started to be decontaminated in that year and was likely not used (in whole or part) for Mg-Th machining. This is problematic, given that NIOSH makes use of DU area air samples and surface smears for D-20/22 to show that the limit of 3E-11 µCi/ml was achieved in the Mg-Th machining operations, without knowing whether those operations

had been relocated relative to these monitors. No further information has been found in recent data captures to resolve this issue.

5. NIOSH needs to provide air monitoring results for the Model Shop, for the period November 1970–1979, before applying the proposed bounding value of 3E-11 μCi/ml for exposures to thorium in the Mg-Th machining operations. SC&A does not agree that air and surface monitoring results from Department 20-D (former Department 22) during the 1962–August 1970 period can be used as an indication that in the period October 1970–1971, "KCP's control of work or in-plant environmental working conditions did not degrade in the years after the cessation of air monitoring," as stated by NIOSH. The Mg-Th machining work after September 1970 took place in the Model Shop, an uncontrolled area, with different Health and Safety Guides. In relation to the single thorium machining air concentration test, done in September–October 1970, SC&A disagrees that there should be reliance on practices performed in the 1971–1979 period based on a single test conducted before the bulk of Mg-Th machining operations took place, even if used as a complement to air monitoring data taken in Department 20-D.

6. In calculating thorium doses, the most claimant-favorable Th-228/Th-232 ratio (0.19 assuming triple separation of thorium, or 0.5 assuming equilibrium) should be chosen for each cancer organ. This item has been acknowledged as a TBD issue.

7. In its response paper, NIOSH has provided adequate information on the composition of Mg-Th alloys.

In summary, SC&A concludes that critical information regarding Mg-Th machining location, workload, and timeframes are lacking for 1963–1970. This information is needed to apply available DU gross alpha monitoring data to corroborate that potential thorium air concentrations are bounded by the proposed air concentration limit of 3E-11 μCi/ml. SC&A further concludes that the lone set of 1970 BZ samples taken in Department 851 are inadequate to demonstrate that the 3E-11 μCi/ml limit was bounding for the Model Shop for 1970–1971. The limit, itself, is found to be very conservative, equating to a calculated 20-year dose equivalent to the bone surface of 1.35 Sv (136 rem) and a 50-year bone surface dose equivalent of 3 Sv (300 rem) for each year of work by a Mg-Th worker. Maximum dose equivalent to the lungs and ET airways are about 30 rem. Whether they would be bounding exposure values cannot be verified in the absence of measurement data or suitable source term exposure modelling.

SC&A recommends that in the absence of such measurement data, NIOSH should validate its proposed 3E-11 μCi/ml air concentration limit through source term-based exposure modelling, followed by suitable sample dose reconstructions to demonstrate the feasibility of applying this limit for the various operational time periods in question (i.e., 1963–1966, 1966–1970, 1970–1979).

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