Draft Report

ADVISORY BOARD ON RADIATION AND WORKER HEALTH

National Institute for Occupational Safety and Health

Assessment of the Metallurgical Laboratory Special Exposure Cohort (SEC) Petition-00135 with Special Emphasis on the 250-Workday Criterion

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1.1 INTRODUCTION

On December 9, 2008, the National Institute for Occupational Safety and Health (NIOSH) issued its Evaluation Report (ER) of the Special Exposure Cohort (SEC) Petition SEC-00135 for the Metallurgical Laboratory (Met Lab) in Chicago, Illinois. The ER concluded the following:

> *NIOSH lacks sufficient information, which includes specific biological monitoring data, sufficient air monitoring information, or sufficient process and radiological source information, to allow it to estimate with sufficient accuracy the potential internal and external exposures to plutonium, radium, fission products, uranium, and uranium progeny to which the proposed class may have been subjected.*

The NIOSH-proposed class includes all Atomic Weapons Employer (AWE) employees who worked at the Met Lab from August 13, 1942, through June 30, 1946, for a **number of workdays aggregating at least 250 workdays** occurring either solely under this employment, or in combination with workdays with the parameters established for one or more other classes of employees in the SEC.

An exception to the 250-workday requirement is provided in 42 CFR 83.13(c)(3)(i), which states the following:

> *For classes of employees that may have been exposed to radiation during discrete incidents likely to have involved exceptionally high level exposures, such as nuclear criticality incidents or* ***other events involving similarly high levels of exposures resulting from the failure of radiation protection controls, NIOSH will assume for the purposes of this section that any duration of unprotected exposure could cause a specified cancer****, and hence may have endangered the health of members of the class. Presence with potential exposure during the discrete incident, rather than a quantified duration of potential exposure, will satisfy the health endangerment criterion.* [Emphasis added.]

During an Advisory Board (or Board) Meeting in Albuquerque, New Mexico, on February 19, 2009, there was a brief discussion regarding the overall applicability of the 250-workday criterion for the Met Lab SEC class eligibility. Enclosed herein as Appendix A are pages 55–62 of the recorded transcript that relate to the 250-workday issue, along with the Board's directive for S. Cohen and Associates (SC&A) to look into this matter.

The Board's directive to SC&A was followed up by a request by Mr. Ted Katz, the Designated Federal Official, in a memorandum dated March 26, 2009, which is included herein as Appendix B.

Based on statements contained in Appendices A and B, the Board and NIOSH agreed on the following issues:

(1) There were a substantial number of workers at Met Lab who were there for less than 250 workdays.

(2) Operation of Chicago Pile Number One (CP-1) was a planned event and **not** an uncontrolled critical event/operation.

(3) In addition to the startup and operation of CP-1 as a plutonium production reactor, however, the Met Lab was engaged in numerous other radiochemical operations, which is why NIOSH established the SEC class in the first place.

(4) SC&A was directed to review and assess the OCAS Evaluation Report along with other available information in context with the SEC's 250-workday criterion.

1.2 STATEMENT OF PURPOSE

The purpose of this report is to provide a preliminary assessment of the Office of Compensation Analysis and Support (OCAS) ER and related materials, which, in turn, may provide the 250-day Work Group with specific topics for future discussions/decisions regarding the applicability of the 250-workday criterion for the Met Lab and possibly other AWE facilities.

1.3 APPROACH AND METHODS

In addition to the SEC-00135 ER, SC&A reviewed more than five-hundred separate documents/ reports that were listed in behalf of the Met Lab in NIOSH's Site Research Query Database (SRDB). Our review of these and other documents focused on potential information/data regarding the following:

- Source term data and processes at the Met Lab
- Personnel staffing/employment periods
- Existing knowledge regarding radiological risks from external and internal radiation
- Existing regulations/standards/protocols for limiting worker exposures to external and internal radiation
- Available instrumentation and methods used to monitor workers for external and internal exposures
- Personnel monitoring data for external and internal exposures
- Radiological incidents and evidence of acute high-dose external and internal exposures

Presented in the sections that follow are excerpts in the form of quotations and exhibits from select SRDB documents that address each of these topics. Whenever a relevant section of a SRDB document is sufficiently brief, it is also enclosed herein as an exhibit.

2.0 RELEVANT BACKGROUND INFORMATION

The Met Lab consisted of seven locations that were part of the University of Chicago campus. Under contract with the University, the Met Lab officially began operation on August 13, 1942, under the direction of the Manhattan Engineer District (MED). The primary goal for the Met Lab was the design, construction, and operation of the world's first nuclear reactor for the purpose of producing plutonium. The "Chicago Pile Number One," or CP-1, was crudely constructed in an abandoned squash court under the west grandstand of the University's Stagg field. Enrico Fermi, the project's director, described CP-1 as "a crude pile of black bricks and wooden timbers" (CP-1 2008, SRDB Ref. ID 42824).

SRDB Ref. ID 43013 (DOE 2008), entitled *The Manhattan Project: CP-1 Goes Critical*, provides the following description of CP-1 and the first sustained nuclear chain reaction:

> *…The wooden timbers supported a lattice structure that contained over* ***six tons of pure uranium metal****, along with 34 more tons of uranium oxide. The almost 400 tons of black bricks in the assembly were graphite, placed there to serve as moderators; the bricks in two of every three layers had a nodule of uranium inside each of them. The presence of so much "moderating" material might have sounded comforting to outsiders until they learned that the moderators were there to increase the amount of fission produced by the uranium. The only things preventing a fission chain reaction from growing within the pile were a series of cadmium rods inserted into the pile's side to absorb the free neutrons emitted by the radioactive uranium.* ***Unlike most reactors that have been built since, this first one had no radiation shielding and no cooling system of any kind.*** *Fermi had convinced Arthur Compton that his calculations were reliable enough to rule out a runaway chain reaction or an explosion, but, as the official historians of the Atomic Energy Commission later noted, the "gamble" remained in conducting "a possibly catastrophic experiment in one of the most densely populated areas of the nation!"*
>
> *Daily the pile grew, brick by brick. Tests on the early afternoon of December 1st indicated that it was very close to being ready. By that evening, the scientists present were convinced that if they withdrew the cadmium control rods the fission chain reaction in the pile would be self-sustaining. Final preparations for the first test began. The next morning most of the observers found themselves crowded together onto a balcony where squash spectators had once stood, ten feet above the floor on the north end of the room* [see Figure 1]. *Fermi, Compton, Walter H. Zinn, and Herbert L. Anderson were grouped around an instrument console at one end of the balcony; from there they could operate one set of control rods. The only person on the floor of the squash court was George Weil, the man who would physically withdraw the final control rod. If the reaction threatened to grow out of control, Weil could re-insert his control rod, and an automatic control rod would also insert itself if the reaction reached a certain pre-set level. In case of emergency, such as Weil becoming incapacitated or*

> *failure of the automatic control rod, Norman Hilberry stood on the balcony with an improbable nuclear safety device: an axe.*
>
> *In an emergency, he would cut a rope that ran up to the balcony, releasing another emergency control rod into the pile. The last line of defense consisted of a "liquid-control squad" that stood on a platform, ready to flood the pile with a cadmium-salt solution. Taken together, these safety precautions were a strange combination of the high-tech and the ad hoc.*
>
> *After rehearsals, Fermi at 9:54 a.m. ordered the electrically-operated control rods removed. All eyes turned to the array of instruments indicating the pace of the fission reaction within the pile. Shortly after 10:00, Fermi ordered the emergency control rod removed and tied to its rope. At 10:37, Fermi ordered Weil to pull all but thirteen feet of the final rod out of the pile. The pace of the audible clicking from the neutron counters (similar to Geiger counters) increased. Over the next few hours, the pile inched its way toward criticality, Weil gradually removing more and more of the final rod while Fermi monitored his array of instruments. ...At 11:25, Fermi ordered the automatic and emergency control rods reinserted for a final safety check. Ten minutes later, these were both removed in order for the experiment to resume.* ***The neutron counters immediately resumed their clicking, the pace growing and growing until a sudden "whrrrump!" filled the room****. The automatic control rod had slammed home into the pile, having been set too low during the safety check. While everyone present took a few deep breaths, Fermi calmly called for lunch.*
>
> *By 2:00 p.m., everyone had resumed their places. Fermi resumed the slow process of inching toward criticality, more and more of the control rod appearing as Weil slowly withdrew it from the pile. Finally Fermi said to Compton "this is going to do it. Now it will become self-sustaining." ...By this time, the clickety-click of the neutron counter had become a steady hum, too fast for the ear to count. At 3:25 p.m., Weil slid the rod back one more time. As Fermi completed one final calculation, his face broke into a broad smile and he announced "the reaction is self-sustaining." ...*
>
> *Following 28 minutes of operation, at 3:53 p.m. Fermi ordered the emergency control rod replaced.* [Emphasis added.]

Operation of CP-1 was terminated in February 1943, and the nuclear reactor was dismantled and moved to the Argonne National Laboratory, where it was reconstructed as CP-2. CP-2 began operation in March of 1943 for continuing research on reactor designs that led to the large production reactors at Hanford. These produced plutonium needed for the bombs tested at the Trinity site and employed in World War II in Nagasaki.

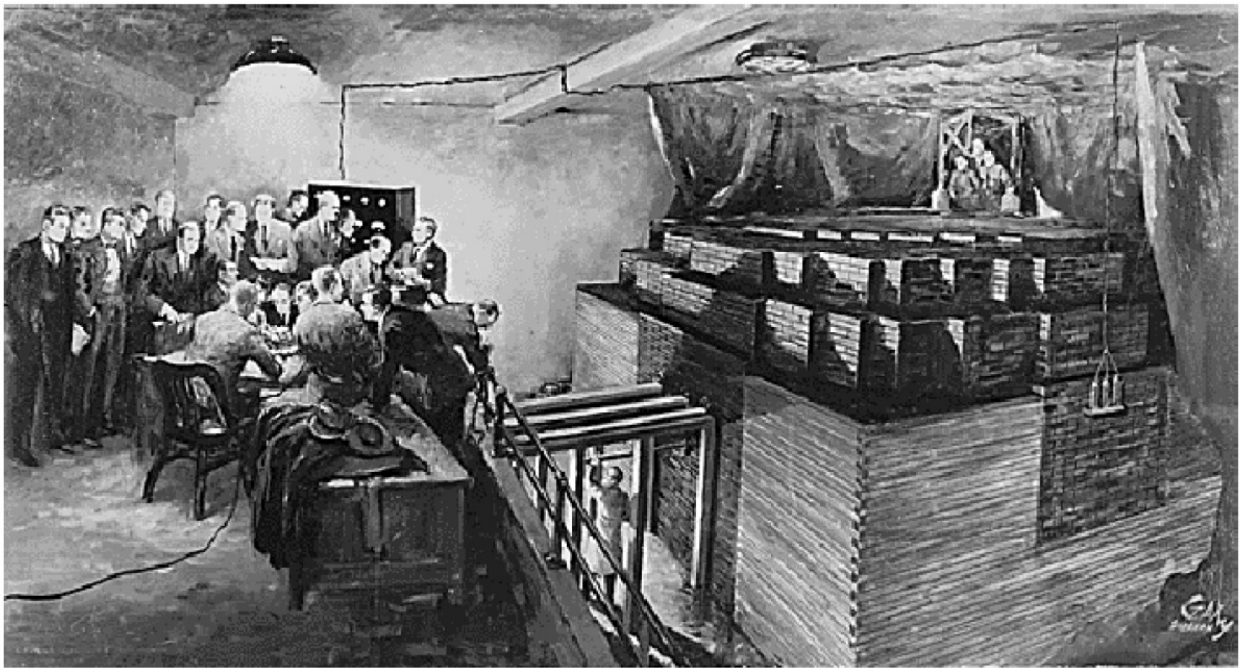


Figure 1. Artist Depiction of First Sustained Nuclear Chain Reaction by CP-1

3.0 THE NEED TO DEVELOP RADIATION CONTROL STANDARDS AND PROTECTIVE MEASURES FOR WORKERS

Before the first sustained nuclear chain reaction was demonstrated on December 2, 1942, radiation source terms and human exposures were largely limited to x-ray machines and radium sources (along with their radioactive daughter products). The introduction of the nuclear reactor, therefore, introduced unprecedented radiological hazards associated with exposures to neutrons, fission products, and activation products, whose potential health effects from external or internal exposure had never been studied.

Because of these uncertain dangers, Dr. A.H. Compton, who was head of the Metallurgical Project, considered it expedient to establish a separate Health Division, along with the Physics, Chemistry, and Technical Division (Stone 1945). In turn, the Health Division was organized into the following three separate lines of responsibilities:

(1) The **Medical Section** conducted human clinical tests with terminally ill patients, and provided routine blood and urine examinations of workers.

(2) The **Biological Research Section** conducted animal studies on the effects of alpha, beta, gamma, and neutron radiation from external sources or internally from the ingestion, inhalation, or trancutaneous assimilation of fission products, plutonium, polonium, and uranium.

(3) The **Health Physics Section** was tasked with developing new instrumentation that could be used to qualify and quantify workplace radiation fields and monitor workers for external and internal exposures.

Early emphasis of establishing exposure limits by the Biological Research Section of the Plutonium Project was based on "tolerance levels" for external radiation, as well as for internal exposures, as described by Dr. Robert Stone, Associate Project Director for Health of the Metallurgical Project, in a 1945 report (Stone 1945):

> *When the Health Division of the Plutonium Project was called into existence in 1942 there were established* ***tolerance doses****, or maximum permissible exposures, for x- and gamma-rays, but it was evident that these rested on rather poor experimental evidence.* ***There was little knowledge of the tolerance for fast neutrons, and none for slow and thermal neutrons, or for alpha or beta rays. Except for radiophosphorus and radiostrontium nothing was known of tolerances of artificial radioactive materials in the body and the knowledge of these two was sparse****. Comparatively little was known even about radium which had caused considerable havoc among radium dial painters. Consequently while the hazards were being estimated, experiments were started to check the calculations and to determine the behavior in the body of the multitudinous radioactive isotopes that were to be created.* [Emphasis added.]

The term “tolerance level” was generally defined as that amount of exposure below which deleterious health effects were unlikely. However, deleterious health effects for consideration were largely those currently defined as **non-stochastic** effects that principally included changes in the cell composition of the peripheral blood. Other indicators included changes in urine constituents, and even changes to or loss of fingerprint patterns that may have resulted from beta radiation to the hands.

3.1 METHODS AND INSTRUMENTATION NEEDED TO MONITOR WORKER EXPOSURE AND DEMONSTRATE COMPLIANCE WITH TOLERANCE LEVELS

The term “Health Physics” was first introduced by the MED to define that discipline in which physical methods are used to determine the hazards to the health of personnel. In a 1945 report entitled *Health Protection Activities of the Plutonium Project*, Dr. Robert Stone, Associate Project Director for Health of the Metallurgical Project, stated the following (Stone 1945, SRDB Ref ID 7693):

On the Use of Pocket Ionization Chambers (PICs) (pp. 7–10):

> *Before the war such hazards as existed were relatively easily controlled. The most wide-spread ones existed in those locations where x-rays and radium were used for medical purposes. In most cases the radiation sources were fixed and protection was built-in…*
>
> *In 1942 when the Health-Physics section was organized, there was still no pile. There were no accumulations of extremely radioactive fission products…*
>
> *It was realized that with a new industry working in unexplored fields with new equipment, it would probably be impossible to keep all possible sources of radiation behind sufficient shielding. …* ***Hence it was necessary to set up personnel monitoring such that some measurement of the amount of radiation reaching each individual could be made****. There were in the market at the time of the beginning of this project a few small ionization chambers that were shaped like fountain pens and could be worn in the pocket.*
>
> *… These instruments are satisfactory for measuring x-rays with an energy of about 200 kv, but the calibration is not entirely accurate for gamma rays. …* ***A great deal of difficulty was found with the—*** *the principle was simple enough, but the application was somewhat complicated. …* ***these instruments were useless for quantitative measures of beta rays, weak x-rays and neutrons.*** [Emphasis added.]

On the Use of Film Dosimeters (pp. 10–11):

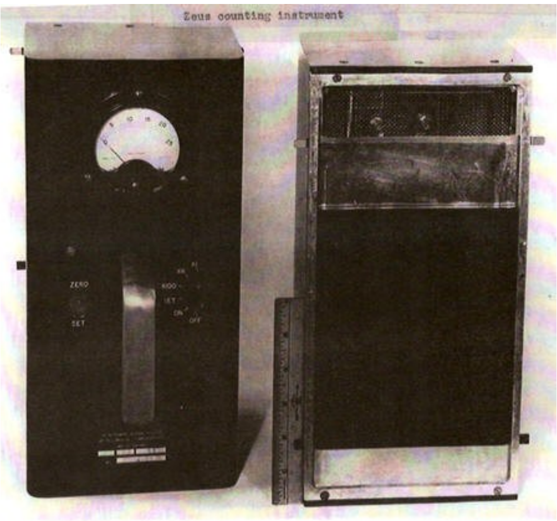
> *The photographic film method of registering exposure to radiation has long been used. Films have varying responses to rays of different energies and therefore are impossible*

> *to calibrate for rays of all energies and types.* ... [however] *after many trials a reasonably satisfactory film meter was evolved.* ... *These films thus acted as a good check against the pocket ionization meters and those who were routinely exposed had to carry both kinds of meters.*

On the Use of Instruments (pp. 11–14):

> *... special apparatus had to be developed for rapidly measuring hands and shoes in such a way as to indicate whether* ***dangerous*** *amounts of material were present. Geiger-Mueller counters, scaling circuits and registers are used in such a way that the fronts and backs of both hands and the soles of the feet are placed in a fixed geometry and counted for an automatically controlled time.*
>
> *... In addition to ionization chambers, Geiger-Mueller counters and proportional counters were used in the work area monitoring, and some warning instruments were placed to detect people with contaminated clothes.*
>
> *Since it was impossible to have fixed monitoring at all points in all buildings, routine surveys of benches, desks, floors, sinks, hoods, etc., were necessary. A group of people had to be specially trained for this job of surveying. Instruments were developed for measuring the alpha radiations for surfaces, the beta and gamma radiations and the radioactive materials in the air. Survey instruments of these kinds had not been needed on any such scale before and hence had to be developed before they could be used.* ***This in itself was a tremendous problem****. If anyone should wonder how contamination could get around to such an extent as to indicate a need for such surveys, let him think how small a droplet of a saturated solution of radium chloride it would take to contaminate a whole laboratory, and then image working with* ***beakers, tubs and vats full of similar material****.*
>
> ***Instrument development problems that faced the Health-Physics section were numerous and were not all solved****, because it was felt that if we could with reasonable assurance keep the radiations in working areas down to low levels that the talents of those capable of developing such instruments would be better applied to instruments for the operation and control of piles and chemical extraction plants.*
>
> *...* ***Many problems have not been solved, or solved only in a crude way****. The measuring of fast, slow and thermal neutrons and of alpha radioactive materials, in terms that will indicate their effectiveness on living tissue, is still in the development stage. ...* [Emphasis added.]

One instrument developed at the Met Lab was the Zeus by W. P. Jesse in 1945. It was an ionization chamber with a sliding thin aluminum or plastic shield over the 5” × 6” detector window located on the bottom of the unit for measuring alpha, beta, and gamma, as shown in Figure 2 below.



Zeus Mark 1, Model 21-A 1945

Figure 2. Survey Instrument Developed at the Metallurgical Laboratory

3.2 TOLERANCE LEVELS FOR EXTERNAL EXPOSURES

For external **photon** exposure, the MED adopted the value of 0.1 R per day (or 30 R/year), which had previously been identified by the National Bureau of Standards in Handbook 20 (NCRP 1936). For persons handling uranium, **beta** radiation to the skin of the hands was limited to 0.5 R/day (or 150 R/yr).

The tolerance level of 0.1 R per day (or 30 R/year) also became a **reference value** for other types of radiation (including external and internal sources that emitted neutrons, protons, and alpha particles). Because it was recognized that for a given dose, high-linear energy transfer (LET) radiation posed greater hazards than photons, the tolerance levels for neutrons (and alpha radiation) were adjusted to reflect their relative biological effectiveness.

For neutrons (and alpha particles), the higher LET values reduced the daily photon exposure value of 0.1 R/day to 0.025 Roentgen Equivalent Physical (REP). **Implicit in this tolerance level for external neutrons was a quality factor of 4**.

Based on LET considerations and calculated on the energy required per ion pair, the MED derived the following theoretically derived tolerance levels for **neutron** exposure, as defined in Table 1:

Table 1. Tolerance Levels for Neutron Flux by Energy
(Source: Wirth 1945)

Fast Neutrons (3 MeV to 0.5 MeV) 3 MeV: 200 η/cm^2/sec 2 MeV: 200 η/cm^2/sec 1 MeV: 250 η/cm^2/sec 0.5 MeV: 360 η/cm^2/sec
Slow Neutrons (0.5 MeV to 0.1 eV) 0.5 MeV: 360 η/cm^2/sec 0.1 MeV: 1,000 η/cm^2/sec <0.3 eV: 2,500 η/cm^2/sec
Thermal Neutrons (0.1 eV to 0.01 eV) 0.1 eV: 15,000 η/cm^2/sec 0.03 eV: 25,000 η/cm^2/sec

3.3 TOLERANCE LEVELS FOR AIRBORNE CONTAMINANTS

For tolerance levels of **airborne contaminants**, the MED selected **radon** levels of 100 pCi/l, which represented one-tenth of the exposure that was thought to have produced harmful effects of Czechoslovakian miners. For **Po-210**, a tolerance level of 5×10^{-4} micrograms per cubic meter (or 2.245 μCi/m^3) was derived from animal data. For **plutonium**, an air concentration tolerance level of 0.35 μCi/m^3 was adopted, which was based purely on computational comparisons of radiation emissions between plutonium and radium. (**At the time, it was assumed that radium per unit activity was 10 times more hazardous than plutonium**.) And for **uranium** (assumedly natural uranium), the MED assigned a tolerance level of 150 µg per cubic meter of air (or 1×10^{-5} μCi/m^3) (USERDA 1946, Bonsib 1942).

3.4 TOLERANCE LEVELS FOR ABSORBED RADIONUCLIDES IN BODY

For tolerance levels of radioactive contaminants in the **body/tissues**, tolerance levels for absorbed quantities of select radionuclides were based on animal data and extrapolation to man. The MED established the following radionuclide-specific tolerance levels (i.e., permissible body burdens):

- Radium: 0.1 µg (or ~0.1 µCi)
- Polonium: 0.15 µg (or 673 µCi)
- Plutonium: 1.0 µg (or 6.13×10^4 pCi)

3.5 TOLERANCE LEVELS FOR URINARY EXCRETION

For **urinary excretion**, tolerance levels had been established only for **polonium** at 5,000 dpm for a 24-hour urine volume.

3.6 TOLERANCE LEVELS FOR INGESTION OR INHALATION

Lastly, **tolerance amounts** for the **ingestion** or **inhalation** and the **maximum permissible concentrations in air** that can be breathed without exceeding the tolerance concentrations in a specified tissue [i.e., bone (B), lung (L), thyroid (T), and external whole body (E)] were derived for mixed fission products, strontium, iodine, and xenon, as shown in Exhibit 1. Important to note is that tolerance levels were not only specified for continuous daily intakes/exposure, but also for a single 1-day intake/exposure. For example, as much as 135 µCi of I-131 could be inhaled or ingested in a single day as a "one-time" tolerable intake.

Exhibit 1. Tolerance Amounts for Ingestion, Inhalation, and Maximum Permissible Concentrations in Air

(Source: Radiation Standards, undated, SRDB Ref ID: 40381)

amount that quantity which will not exceed the safe irradiation dose to <u>any</u> tissue, whether it be gut, lung, bone, etc. In the following table are listed the tolerance amounts for ingestion or inhalation, and the maximum permissible concentrations in air that can be breathed without exceeding the tolerance concentrations in one or another tissue.

Material		Tolerable amount in μC, to be taken Once	Daily	Max. Conc. in μC/l., to be inhaled for 8 hour. per day: One day	Daily
Mixed (200 days, 0.9 Mev)	Swallowed (a)	300 (B)^1	1.0(B)^1	-	-
	Inhaled (b)	4.4 (L)^1	0.015(L)^1	0.0009	0.000003(L)^1
Strontium	Swallowed (c)	70 (B)^1	1.0 (B)^1	-	-
(55 days, 0.6 Mev)	Inhaled (b)	6.6 (L)^1	0.08(L)^1	0.0014	0.000016(L)^1
Iodine (8 days, 0.15 Mev)	Swallowed (d)	135 (T)^2	1.2 (T)^3	-	-
	Inhaled (d)	135 (T)^2	1.2 (T)^3	0.028	0.0003 (T)^3
Xenon	Swallowed	-	-	-	-
	Inhaled	-	-	0.14 (E)^3	0.014 (E)^1

(a) 1% deposited in bone, no excretion

(b) 50% remains in lung, " "

(c) 7% deposited in bone, " "

(d) 20% deposited in thyroid, no excretion

^{1}To reach 0.1 r/day max. rate

^{2} " " 10 r/day " "

^{3} " " 1 r/day " "

The figures in row 1 (for "mixed" material) have been calculated on the assumption that the average half-life and energy of the mixed fission products are those of Ruthenium (200 days and 0.9 Mev), with 2% and 50% absorption from the gut and lung into the blood, half of this being deposited in the bone and not subsequently excreted. The tissue setting the tolerance value is indicated by the letter in parentheses, B for bone, L for lung, T for throid, E for exterior of body.

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4.0 COMPARISON OF TOLERANCE LEVELS TO CURRENT STANDARDS

Tolerance levels established in behalf of Met Lab workers and others were based on limited scientific data that over the past 60-plus years have exponentially increased and revised our understanding of the dose response relationship with regard to human health risks. Perhaps equally significant was the shift from tolerance levels associated with non-stochastic effects to regulatory standards that are largely based on stochastic health risks. As summarized below, current exposure limits are well below those of tolerance levels applicable to Met Lab workers.

4.1 COMPARISON OF TOLERANCE LEVELS FOR EXTERNAL EXPOSURES TO CURRENT STANDARDS

For penetrating whole-body photon exposures, the tolerance levels of 0.1 R/day (or 30 R/yr) is approximately 6 times the current yearly regulatory dose limit of 5 rem.

For skin exposures to the extremities from betas, the 0.5 R/day (or 150 R/yr) is about 3 times the current regulatory limit of 50 rem/yr.

Table 1 in Section 3.2 cited neutron flux values by energy that were considered tolerance values for continuous neutron exposures. Table 2 compares these values to current regulatory values defined by the Nuclear Regulatory Commission (NRC)/Department of Energy (DOE). On average, tolerance values permitted workers to be exposed to neutron flux dose equivalents that were more than 10 times the current values given in the last column of Table 2.

Table 2. Comparison of Tolerance Levels with Current Regulatory Values for Neutron Exposures

Neutron Energy	Tolerance Levels (η/cm^2/sec)	Current Standards[*] (η/cm^2/sec)	Tolerance Level/ Current Standard
3 MeV	200	20	10
2 MeV	200	20	10
1 MeV	250	18	14
0.5 MeV	360	30	12
0.1 MeV	1,000	80	12
0.3 eV	2,500	670	4
0.1 eV	15,000	670	22
0.03 eV	25,000	670	37

[*] Current values are flux values corresponding to 100 mrem per 40 hours or 5,000 mrem/2,000 workhours.

4.2 COMPARISON OF RADON TOLERANCE LEVELS IN AIR TO CURRENT LIMITS

Section 3.3 identified a tolerance level of 100 pCi/liter of air for radon for continuous exposure. This value was specified without consideration to the equilibrium fraction between radon and its short-lived daughter products.

If radon is assumed to be in full equilibrium with its short-lived progeny, continuous exposure at 100 pCi/l is about 3 times the current exposure limit of 4 working level months per year (4 WLM/yr). At 50% equilibrium, the tolerance level is 1.5 times the current limit.

4.3 COMPARISON OF THE RADON BREATH CONVERSION VALUE USED BY NIOSH TO THAT OF THE MET LAB

An assessment of radium body burden by means of radon breath analysis requires a conversion factor by which the activity of Rn-222 in exhaled air is converted to activity of Ra-226 in the body. By means of experimental data and their interpretation, Met Lab personnel derived a conversion value of 1 pCi/l of radon in exhaled air to correspond to 0.1 microgram (or ~0.1 µCi or 1×10^5 pCi) of Ra-226 in the body (Tybout 1945).

The Met Lab conversion factor is 2.52 times lower than the conversion factor assumed/employed by NIOSH, as given in ORAUT-OTIB-0025 (ORAUT 2005). OTIB-0025 cites a conversion value of 252,000 pCi of Ra-226 in body for each pCi/l of radon in exhaled air. In brief, the Ra-226 body burden of Met Lab workers assessed by radon breath analysis would have been underestimated by a factor of 2.52.

4.4 COMPARISON OF AIR TOLERANCE LEVELS TO CURRENT DERIVED AIR CONCENTRATIONS (DACs)

When compared to present-day derived air concentration (DAC) values, the air tolerance levels for continuous 8-hour per day exposure levels varied dramatically, as shown in Table 3. Because uranium was regarded as primarily a chemical toxin, the ratio between the tolerance level and DAC was lowest at 2. Most serious discrepancies between tolerance levels and DACs were for Po-210 and Pu-239/240, which differed by factors of 7,483 and 50,000, respectively.

Table 3. Comparison of Air Tolerance Levels to Current DAC Values

Radioelement	Tolerance Level (µCi/m^3)	DAC (µCi/m^3)	Ratio of Tolerance Level/DAC
Sr-90	1.6×10^{-2}	2×10^{-3}	8
I-131	0.3	2×10^{-2}	15
Po-210	2.245	3×10^{-4}	7,483
U-238/234	1×10^{-5}	2×10^{-5}	2
Pu-239/240	0.35	7×10^{-6}	50,000

4.5 COMPARISON OF INHALATION/INGESTION TOLERANCE LEVELS TO CURRENT ORGAN DOSE LIMITS

Of significance to inhalation ingestion tolerance levels, as shown in Exhibit 1, are quantities of radionuclides that could be either inhaled or ingested on a "one-time" basis, with the assumption that no additional intake would be permitted for a 1-year period.

For example, Exhibit 1 shows a maximum air concentration of 0.028 μCi/l of I-131 that a person may breathe for 8 hours as a one-time inhalation exposure. This air concentration converts to a total inhalation of 269 μCi of I-131.

$$\text{Inhalation of I-131 } (\mu\text{Ci/day}) = (0.028\ \mu\text{Ci/l})(1000\text{l/m}^3)(1.2\ \text{m}^3\text{/hr})(8\ \text{hr/day}) = 269\ \mu\text{Ci}$$

By means of the Environmental Protection Agency (EPA) dose conversion factor of 1.08 rem/μCi inhaled (EPA 1988), the **one-time inhalation of 269 μCi of I-131 translates to a thyroid dose of 290 rem** that is delivered over about a 1-month period.

Equally, Exhibit 1 shows that an individual may continuously breathe air levels of 0.0003 μCi/l of I-131 (or 0.3 $\mu\text{Ci/m}^3$). For a year consisting of 2,000 work-hours and a breathing rate of 1.2 m^3/hr, the annual tolerance intake of 720 μCi of I-131 is estimated, which yields an annual thyroid dose of 777 rem.

These values must be compared to the current regulatory limit of 50 rem to the thyroid.

4.6 ASSESSMENT OF TOLERANCE LEVELS OF RADIOCONTAMINANTS IN BODY

The *Manhattan District History, Book I, Volume 7, Medical Program* (USERDA 1946), stated the following on page 2.12:

> *It is obvious that people working with these radioactive substances would inadvertently ingest and inhale these substances to some degree. It was necessary, therefore, as an additional precautionary measure, to monitor the personnel to make certain that they had not accumulated more than the maximum allowable concentration of these substances in their body tissues. Tolerance levels for* ***absorbed*** *quantities of these radioactive materials were therefore derived from animal experimentation and extrapolated from these values to man…* [Emphasis added.]

As summarized in Section 3.4, the MED defined tolerance body burdens for radium, polonium, and plutonium of 0.1 μg (or 0.1 μCi), 0.15 μg (or 673 μCi), and 1.0 μg (or 6.13×10^{-2} μCi), respectively.

By assuming a body burden defined by these tolerance levels for even a brief period of time, SC&A derived the following organ doses by means of IMBA (Integrated Modules for Bioassay Analysis), as shown in Tables 4, 5, and 6.

Inspection of Tables 4, 5, and 6 shows that even the **transient absorbed quantities** (or body burdens of tolerance levels) of Ra-226, Po-210, and Pu-239 yield organ doses in the tens, hundreds, and thousands of rem. Because tolerance levels were not restricted by a duration of exposure, derived organ doses in Tables 4, 5, and 6 could, therefore, be the result of a single acute exposure event.

Table 4. Select Organ Doses Resulting from a One-Time Body Burden of 0.1 µg (or 0.1 µCi) of Ra-226 (Type M) as a Function of Time*

Year	Organ Doses (Rem)		
	Lung	Bone Surface	RBM
1	293	23	2.6
5	302	63	7.2
10	302	96	10.1
20	302	123	11.3

* The **body burden** of 0.1 µCi was the result of an acute inhalation exposure as determined by a WBC.

Table 5. Select Organ Doses Resulting from an Acute Exposure and Ingestion Exposure that Yielded a Transient Absorbed (Body Burden) of 673 µCi of Po-210 (Type M; f1 of 0.1)

Year	Organ Doses (Rem)		
	Lung	Bone Surface	RBM
1	32,280	63,400	2660
5	32,833	63,464	2661
10	32,833	63,646	2661

Table 6. Select Organ Doses Resulting from a One-Time Body Burden of 1.0 µg (or 6.13×10^{-2} µCi) of Pu-239 (Type S) as a Function of Time*

Year	Organ Doses (Rem)		
	Lung	Bone Surface	RBM
1	124	0.4	2.9
5	177	5.2	6.5
10	193	14.3	8.3
20	205	35.7	10.5

* The **body burden** of 6.13×10^{-2} µCi of Pu-239 was the result of an acute inhalation exposure as determined by a chest count.

4.7 ASSESSMENT OF TOLERANCE LEVELS OF Po-210 IN URINE

Until December 31, 1946, the MED defined tolerance values for uranium excretion for only Po-210 at 5,000 dpm in a 24-hour urine sample.

Under a steady-state of daily urine excretion of 5,000 dpm representing a **6-month inhalation** or **ingestion** exposure period, SC&A derived the following organ doses using IMBA.

Inspection of Table 7 shows that for a 6-month exposure to Po-210 that resulted in a steady-state excretion rate of 5,000 dpm per day, organ doses as high as 1,500 rem would have resulted.

Table 7. Organ Doses Corresponding to a Steady-State Po-210 Urine Excretion Rate of 5,000 dpm/24-Hours for a 6-Month Exposure Period

Organ	Cumulative Dose (Rem)		
	1 Year	2 Year	3 Year
Inhalation			
Lung	1,581.00	1,590.25	1,590.42
Kidneys	209.30	215.85	215.95
LLI	108.10	111.48	111.54
Ingestion			
Liver	101	102	102
Kidneys	196	198	198
LLI	8.25	8.25	8.25

5.0 EVIDENCE OF POTENTIALLY HIGH EXPOSURES AND/OR EXPOSURES IN EXCESS OF ESTABLISHED TOLERANCE LEVELS

Our review of the more than 500 reports/documents identified in the SRQD for the Met Lab largely confirmed the fact that available individual monitoring data are insufficient for dose reconstruction, as concluded by NIOSH in the Petition SEC-00135 ER.

However, among some of the reports reviewed, there exists a substantial number of documented incidents in which Met Lab personnel either received doses in excess of tolerance levels or were exposed to radiological conditions that are of relevance to the 250-day criteria. Presented below are examples of such incidences.

5.1 EXAMPLES OF EXTERNAL EXPOSURES IN EXCESS OF TOLERANCE LEVELS

From Nickson 1943: *Notes of Meetings in Regard to Radiation Hazards of Project Personnel*, dated October 28, 1943, the following statements appear:

> *In this meeting some of the hazardous points on the Project were discussed. By and large the hazards referred to were those of radiation. ...* [Employee's] *group was discussed. It was discovered that a total of* ***5 grams*** *of radium was in their possession... Examination of* [this group's] *badge reading for the past six weeks on these individuals showed some had exceeded 0.6 r during any week ...* [Employee X] *has recently started work in a room in Ryerson with a* ***1 gram source****.* [The employee's] *last recorded* [blood] *count is 9-28-43 at which time* [the employee's] *white blood count was 6700, with no abnormalities of the reds or differential.* [The employee's] *hemoglobin is 13.5 grams. An interview with* [the employee] *revealed that* [the employee's] *source to date with which* [the employee] *has done a little work, is* ***inadequately shielded, so much so that a tolerance dose is received in the room above which*** **[the employee]** ***is working, in two hours.*** *The problem of more adequate shielding for both [employee] and those in the room above* [the employee] *has been considered and is at present being constructed.* ***However, in the course of*** **[the employee's]** ***problem*** **[the employee]** ***will be required to move the source from the experimental apparatus to a place of adequate storage several times a day****. At present* [the employee] *is planning to move the source with an arrangement which does not get it more than arm's length from* [the employee's] *body. The question of devising and using tongs has been discussed with [employee].* [The employee] *agreed to do so.* ***It was pointed out to*** **[the employee]** ***that with*** **[the employee's]** ***present procedure it can be calculated that*** **[the employee's]** ***body will receive on the order of an r for each removal from the apparatus or from its place of storage.***
>
> ***In view of the nature of*** **[the employee's]** ***experiments and in view of the inadequate shielding at present it is my feeling that*** **[Employee X]** ***should***

> ***receive weekly white counts, differentials, platelet counts, and total counts including a reticulocyte count along with the above every two weeks***.
>
> ... [Employee] *is known to have been working with a hot solution… and it was revealed* [the employee's] *so-called* ***dirty room****, in which highly active materials were kept, is now being revised with the installation of a lead safe* … [Emphasis added.]

These statements suggest that "Employee X" was expected to move a 1-gram radium source several times in a single day. This would have resulted in an external exposure of several roentgens in a single day. Lesser doses of 100 mR every 2 hours would also have been received by personnel working in the room above.

5.2 POTENTIALLY HIGH EXTERNAL EXPOSURES ASSOCIATED WITH THE OPERATION OF CP-1

Although SC&A found no specific data regarding external photon and neutron dose rates/ exposures associated with the operation of CP-1, a search regarding instrumentation developed and employed during the early period of the Manhattan Project cited the need for instruments capable of measuring the very high dose rates with open experimental ports in the pile to which scientists/engineers may have inadvertently exposed themselves, as noted in Exhibit 2 and quoted below.

> *… It turned out that the scientist and engineers were so interested in their work that they often overlook the radiation hazard. Uranium, which is used in the piles, was not very radioactive. However, when irradiated it produced fission products and plutonium, which cause a more series* [sic] *radiation hazard. It was also noted that a* ***worker walking by an experimental hole in the pile would not suffer an immediate reaction, but could receive a high dose which would show up a few days later.*** [Emphasis added.]

Exhibit 2. Portable Radiation Instruments Used at Met Lab

Zeuto 1940s

The Oak Ridge pile at the Clinton Engineer Works (later became the Oak Ridge National Laboratory) began operating on November 2, 1943. It turned out that the scientist and engineers were so interested in their work that they often overlook the radiation hazard. Uranium, which is used in the piles, was not very radioactive. However, when irradiated it produced fission products and plutonium, which cause a more series radiation hazard. It was also noted that a worker walking by an experimental hole in the pile would not suffer an immediate reaction, but could receive a high dose which would show up a few days later. As such, instrumentation needed to be developed that could measure higher and higher exposure rate levels. The exposure rate levels were increasing rapidly from mR/h from basic studies to 100's or 1,000's of R/h for fission products in plutonium production reactors.

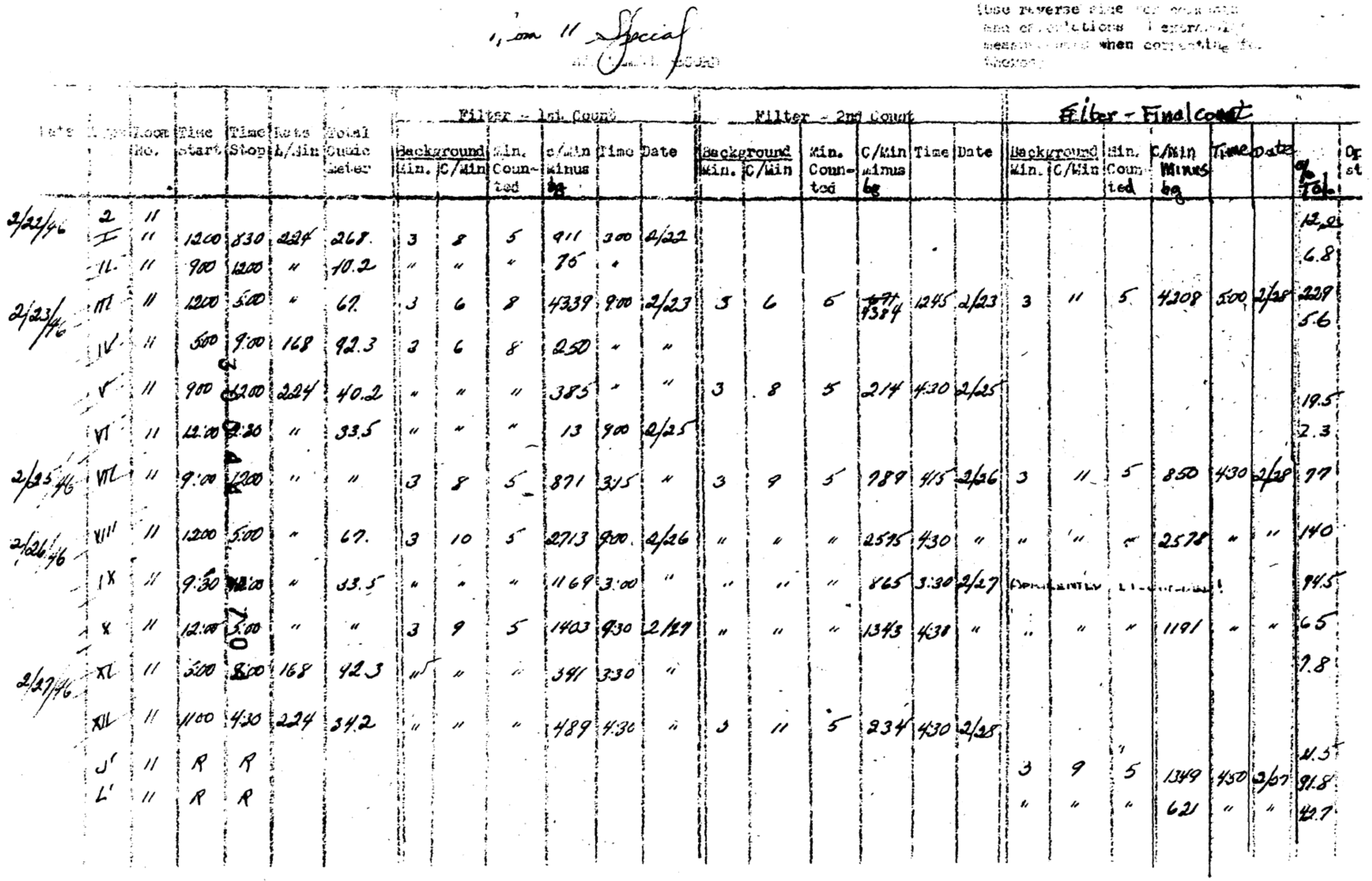
5.3 AIR SAMPLING DATA/INSPECTION REPORTS

Uranium metal production was a major part of the Manhattan Project. In order to determine the potential hazards in the handling of materials, various facilities linked to the Project were visited and evaluated regarding worker safeguards, as described in a December 1942 report (Bonsib 1942). In behalf of the Met Lab, the report provided the following observations:

> *Practically all of the work in the shops and laboratories visited is concerned with the metal. The shop in **Eckhart Hall** is in the basement and is very crowded. The ventilation, which is dependent solely upon any air that might come through or around tightly closed windows and a single door, is **exceedingly bad**. It is **urgent** that this shop be moved out of its present location so that the **health of those** engaged in this work may be better safeguarded. If this is not feasible then adequate ventilation should be PROMPTLY installed. ... It is undesirable for men milling or working on the metal to **smoke without first washing their hands** as some of the metal may be ingested.* [Emphasis added.]

A review of air sampling data reported in 1946 (or more than 3 years after these documented observations) indicates numerous locations and times where air concentrations were well above tolerance levels (Air Sampling 1946, SRDB Ref ID: 16801). For example, Exhibit 3 shows that Room 11 had an air concentration of 229% of tolerance levels on February 28, 1946, and 140% on February 26, 1946.

Exhibit 3. Air Sampling Data from Room 11



Room 11 Special

(Use reverse side [illegible] of calculations [illegible] measurement [illegible] when correcting [illegible])

Date	[illegible]	Room No.	Time start	Time Stop	Rate L/Min	Total Cubic Meter	Filter - 1st Count: Background Min.	Background C/Min	Min. Counted	C/Min minus bg	Time	Date	Filter - 2nd Count: Background Min.	Background C/Min	Min. Counted	C/Min minus bg	Time	Date	Filter - Final count: Background Min.	Background C/Min	Min. Counted	C/Min Minus bg	Time	Date	% Tol.	Op st
2/22/46	2	11																								
	I	11	1200	830	224	268.	3	8	5	911	300	2/22													12.21	
	II.	11	900	1200	"	10.2	"	"	"	76	"														6.8	
2/23/46	III	11	1200	5:00	"	67.	3	6	8	4339	9:00	2/23	3	6	6	~~[illegible]~~ 4384	1245	2/23	3	11	5	4208	500	2/28	229	
	IV	11	500	9:00	168	92.3	3	6	8	250	"	"													5.6	
	V	11	900	1200	224	40.2	"	"	"	385	"	"	3	8	5	214	4:30	2/25							19.5	
	VI	11	12:00	2:30	"	33.5	"	"	"	13	900	2/25													2.3	
2/25/46	VII	11	9:00	1200	"	"	3	8	5	871	3:15	"	3	9	5	789	4:15	2/26	3	11	5	850	430	2/28	77	
2/26/46	VIII	11	1200	5:00	"	67.	3	10	5	2713	9:00	2/26	"	"	"	2595	430	"	"	"	"	2578	"	"	140	
	IX	11	9:30	12:00	"	33.5	"	"	"	1169	3:00	"	"	"	"	865	3:30	2/27	APPARENTLY [illegible]!						94.5	
	X	11	12:00	3:00	"	"	3	9	5	1403	9:30	2/27	"	"	"	1343	4:30	"	"	"	"	1191	"	"	65	
2/27/46	XI	11	5:00	8:00	168	42.3	"	"	"	341	3:30	"													7.8	
	XII	11	1100	4:30	224	34.2	"	"	"	489	4:30	"	3	11	5	234	430	2/28							11.5	
	J'	11	R	R															3	9	5	1349	450	2/27	91.8	
	L'	11	R	R															"	"	"	621	"	"	42.7	

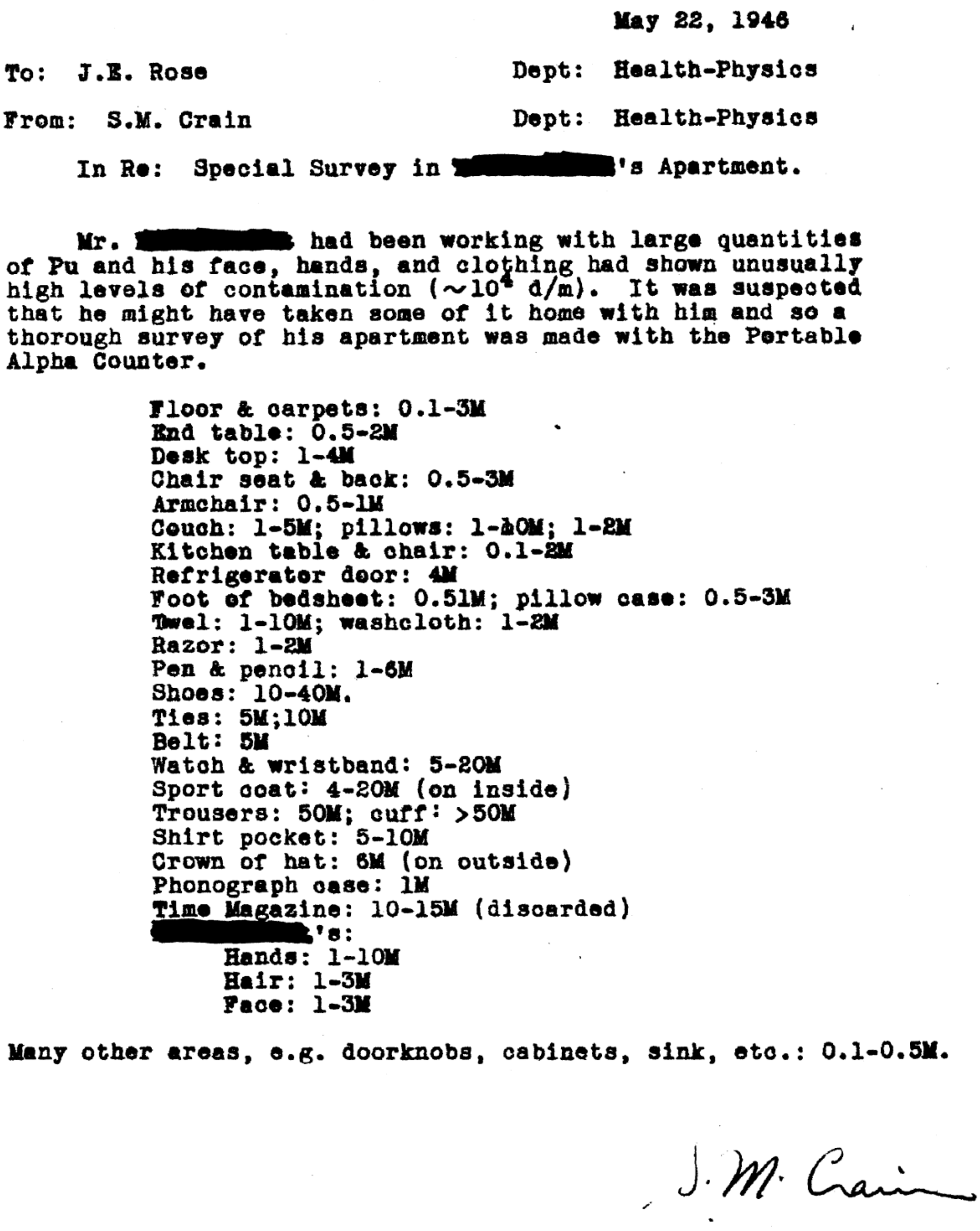
5.4 PU CONTAMINATION SURVEYS OF WORKERS' RESIDENCES

In April and May of 1946, the personal residences of three workers (designated herein as Workers A, B, and C) were surveyed by the Health Physics Section for plutonium contamination (Crain 1946). Results of these surveys are enclosed as Exhibits 4, 5, and 6. Inspection of Exhibit 4 identifies that Worker A "…had been working with large quantities of Pu and [the employee's] **face**, **hands**, and **clothing** had shown unusually high levels of contamination (~10^4 d/m) …" [Emphasis added.]

The survey of Worker A's apartment on May 22, 1946, with a portable alpha counter yielded variable levels of surface contamination reported in the undefined unit of "M." Among the highest levels of contamination was an assortment of clothing items, shoes, wristwatch, and a magazine.

Lower, yet substantial, levels of alpha contamination were also found in the personal residence of Worker B and Worker C on May 11, 1946, and April 29, 1946, respectively, as shown in Exhibits 5 and 6.

Exhibit 4. Survey of Worker A's Apartment



May 22, 1946

To: J.E. Rose Dept: Health-Physics

From: S.M. Crain Dept: Health-Physics

In Re: Special Survey in [redacted]'s Apartment.

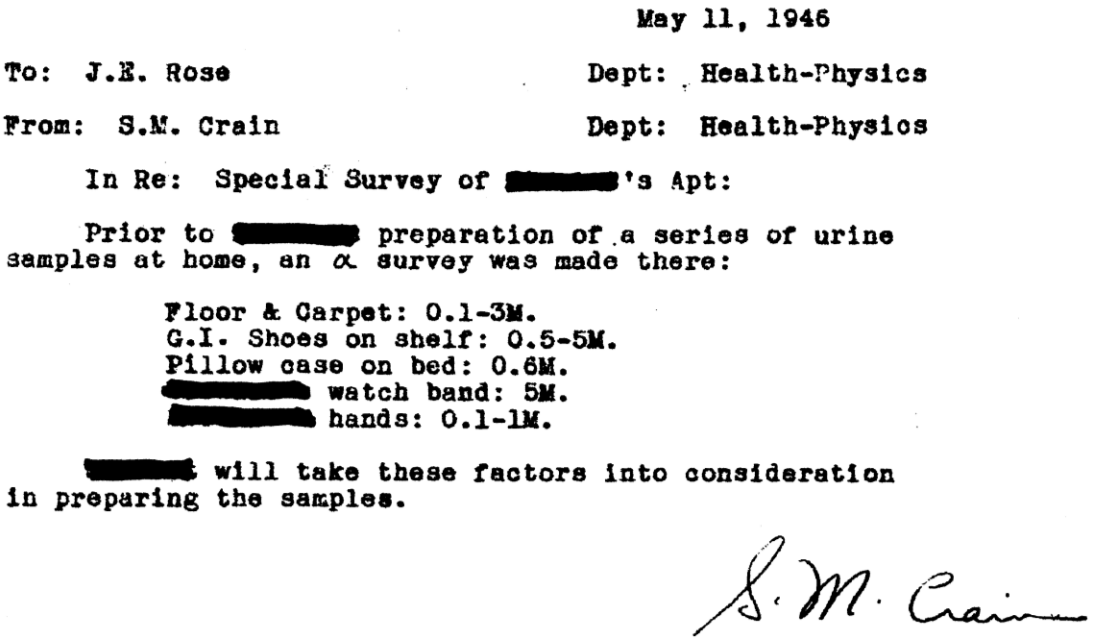
Mr. [redacted] had been working with large quantities of Pu and his face, hands, and clothing had shown unusually high levels of contamination ($\sim 10^4$ d/m). It was suspected that he might have taken some of it home with him and so a thorough survey of his apartment was made with the Portable Alpha Counter.

Floor & carpets: 0.1-3M
End table: 0.5-2M
Desk top: 1-4M
Chair seat & back: 0.5-3M
Armchair: 0.5-1M
Couch: 1-5M; pillows: 1-10M; 1-2M
Kitchen table & chair: 0.1-2M
Refrigerator door: 4M
Foot of bedsheet: 0.51M; pillow case: 0.5-3M
Towel: 1-10M; washcloth: 1-2M
Razor: 1-2M
Pen & pencil: 1-6M
Shoes: 10-40M.
Ties: 5M;10M
Belt: 5M
Watch & wristband: 5-20M
Sport coat: 4-20M (on inside)
Trousers: 50M; cuff: >50M
Shirt pocket: 5-10M
Crown of hat: 6M (on outside)
Phonograph case: 1M
Time Magazine: 10-15M (discarded)
[redacted]'s:
  Hands: 1-10M
  Hair: 1-3M
  Face: 1-3M

Many other areas, e.g. doorknobs, cabinets, sink, etc.: 0.1-0.5M.

S. M. Crain

Exhibit 5. Survey of Worker B's Apartment



May 11, 1946

To: J.E. Rose Dept: Health-Physics

From: S.M. Crain Dept: Health-Physics

In Re: Special Survey of [redacted]'s Apt:

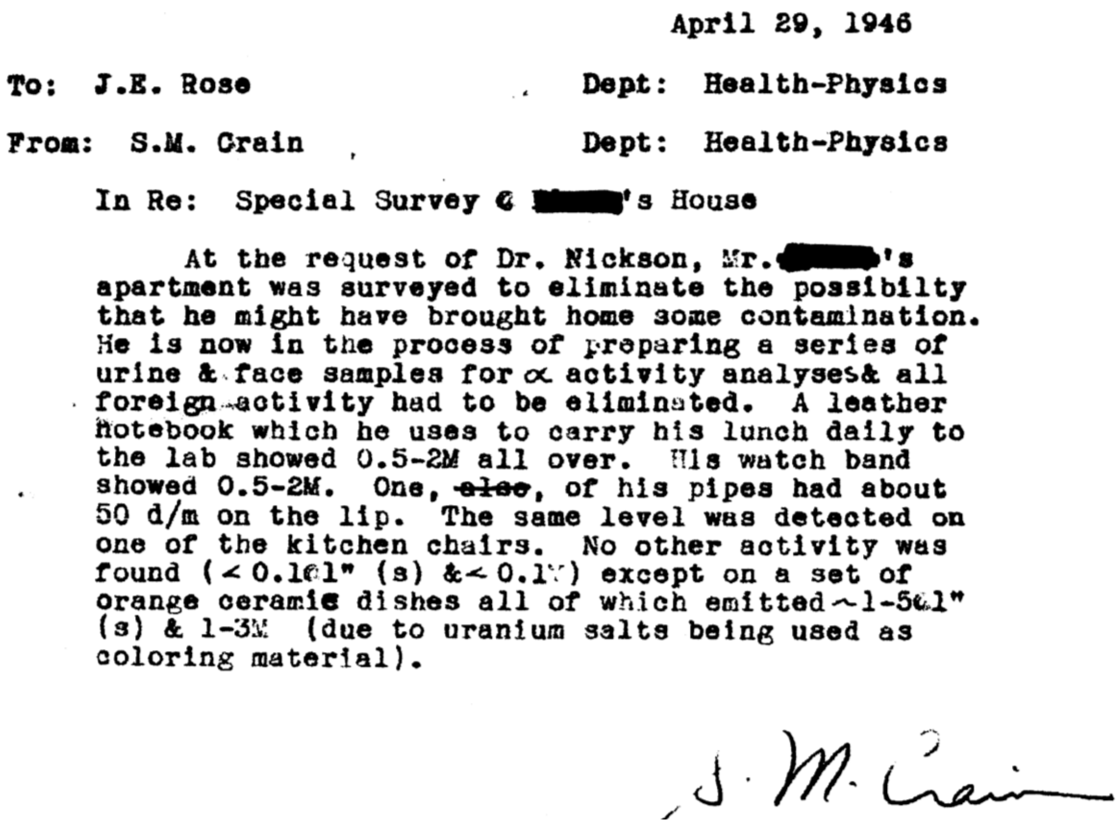
Prior to [redacted] preparation of a series of urine samples at home, an α survey was made there:

Floor & Carpet: 0.1-3M.
G.I. Shoes on shelf: 0.5-5M.
Pillow case on bed: 0.6M.
[redacted] watch band: 5M.
[redacted] hands: 0.1-1M.

[redacted] will take these factors into consideration in preparing the samples.

S. M. Crain

Exhibit 6. Survey of Worker C's Apartment



April 29, 1946

To: J.E. Rose Dept: Health-Physics

From: S.M. Crain Dept: Health-Physics

In Re: Special Survey @ [redacted]'s House

At the request of Dr. Nickson, Mr.[redacted]'s apartment was surveyed to eliminate the possibilty that he might have brought home some contamination. He is now in the process of preparing a series of urine & face samples for α activity analyses& all foreign activity had to be eliminated. A leather notebook which he uses to carry his lunch daily to the lab showed 0.5-2M all over. His watch band showed 0.5-2M. One, ~~also~~, of his pipes had about 50 d/m on the lip. The same level was detected on one of the kitchen chairs. No other activity was found (< 0.1c1" (s) & < 0.1M) except on a set of orange ceramic dishes all of which emitted ~1-5c1" (s) & 1-3M (due to uranium salts being used as coloring material).

S. M. Crain

SC&A Comments

A substantial investigative effort was made by SC&A to identify the type of portable survey instrument used, in the hope of decoding the undefined surface contamination unit of "M" reported in Exhibits 4, 5, and 6.

Based on the times of the three surveys (i.e., April 29, May 11, and May 22, 1946), SC&A believes that it was the "Zeuto" Alpha Meter developed at the University of Chicago's Met Lab and used from 1943 to 1946 (see Exhibit 7).

Inspection of Exhibit 7 also identifies the fact that the "Zeuto's" readout scale of 1–5 and 10–50 were unitless and required the use of a calibration curve for interpretation, as given by the following statements cited in Exhibit 7:

> *…A calibration curve dated* ***March 26, 1946****, is taped on the left end of the instrument. It converts the* ***unitless*** *reading on the meter into disintegration per minute.* [Emphasis added.]

Without the benefit of the instrument's specific calibration curve, a definitive interpretation of the "M" unit is not possible. However, in comparing the general reference value of ~10^4 d/m contamination levels to Worker A's face, hands, and clothing to the itemized contamination levels listed at the bottom of Exhibit 4, an approximate conversion is that 1 M ≈ 1,000 dpm.

A more difficult challenge, however, is to further extrapolate the converted "M" value into the conventional units of dpm/unit area, such as dpm/100 cm^2. This is especially true for those measurements in which the individual items represented a contaminated surface area that was substantially less than the instrument's sensitive area assumed to represent 3" by 5".

Lastly, these high levels of contamination found in the private residences of these workers can only serve as indirect evidence of the potentially large quantities of plutonium that were likely inhaled/ingested.

Exhibit 7. Zeuto Alpha Survey Meter

(Source: ORAU 1999)

"Zeuto" Alpha Meter from the Metallurgical Laboratory (1943-1946)

The Zeuto seems to have been the second survey instrument designed exclusively for measuring alpha contamination (the first was the "Pluto"). It was developed by Francis Shonka at the University of Chicago's Metallurgical Laboratory during World War II. "Zeuto" is a combination of the names "Zeus" (another survey instrument developed by Shonka) and "Pluto."

The identification towards the lower left of the photo reads "An Instrument Section Product, Metallurgical Laboratory, Univ. of Chicago." A calibration curve dated March 26, 1946 is taped on the left end of the instrument. It converts the unitless reading on the meter into disintegrations per minute.

The original description of the Zeuto is found in MDDC-117.

Chamber: 1" × 5" × 3", thin plastic window protected by wire screen on bottom (ca. 3" × 5")

Range: 0–5 (no units)

Size: 5.5" × 10.5" × 4.5"

Donated by [Redacted]

NOTICE: This report has been reviewed for Privacy Act information and has been cleared for distribution. However, this report is pre-decisional and has not been reviewed by the Advisory Board on Radiation and Worker Health for factual accuracy or applicability within the requirements of 42 CFR 82.

5.5 PLUTONIUM IN FECAL SAMPLES

In a monthly summary report dated June 20, 1946, the Biochemical Survey Section provided the following information (Russell 1946).

> *In a preliminary survey of a few persons of the Metallurgical Laboratory,* ***single fecal specimens*** *were found to contain as much as 200 α c/min. Some of these individuals were removed from contaminated areas for at least one week and a fecal analysis at the end of this showed only a slight decrease. Even at the end of two weeks one individual having an initial count of ~200 α c/min in a* ***single specimen*** *decreased to only 30 α c/min . . .*
>
> *The question as to whether the plutonium detected in the feces was coming from the lungs or if there was a slow elimination of the ingested material is one which could not be answered since no experiments had been conducted along this line…*

The continued presence of plutonium in fecal samples even up to two weeks following the workers' removal from contaminated areas suggests that (1) inhalation was likely the dominant exposure pathway, and (2) plutonium originally deposited in the upper regions of the respiratory tract continued to be transferred upward and into the GI tract over several days.

By **unconservatively** assuming that (1) a "single fecal specimen" represented a full 24-hour sample, and (2) sample processing and sample counting resulted in a counting efficiency of 50%, SC&A derived the following lung doses shown in Table 8. Derived doses correspond to a single 24-hour fecal sample with an activity of 400 dpm and obtained 1 week following an acute airborne exposure.

Table 8. Lung Doses Associated with Acute Inhalation Exposure of Plutonium as Evidenced by a Positive Fecal Sample*

Year	Lung Dose (Rem)
1	7.2
5	10.0
10	11.3
20	12.0

* Doses were derived in behalf of a 400 dpm Pu activity in a 24-hour fecal sample obtained 1 week after exposure.

5.6 CHANGES IN BLOOD COMPOSITION

In a report entitled *Health, Radiation and Protection – Report for Month Ending May 7, 1943* (Stone 1943; Ref ID 40751), the following observations were briefly cited:

> ***Three workers showed blood changes due to overexposures to radiation.***
>
> ***Blood effects due to handling of radium sources appeared in two workers during the past month****. The cyclotron was responsible for a third worker with a low blood count.* [Emphasis added.]

The report provides no additional data that describe or quantify the "blood effects" in behalf of the five workers. It may be assumed, however, that the observed blood effects and the decision to assign an **overexposure to radiation** as the underlying cause was based on criteria defined in Nickson 1943 (Ref ID 44786).

6.0 DISCUSSION AND SUMMARY CONCLUSIONS

The potential impact of granting a waiver to the 250-workday criterion to Met Lab workers was not exhaustively addressed in this report. However, a preliminary sampling of data suggests that this may include a substantial number of workers.

In a report entitled *Metallurgical Project Personnel* (Compton 1943, SRDB Ref ID: 44477) dated February 26, 1943 (or less than 7 months after facility operation commenced), all Project personnel are identified by name in various categories that include scientists, research associates, research assistants, technicians, craftsmen, laborers, etc.

Pages 6 and 7 of the *Metallurgical Project Personnel* report also identified a total of 169 individuals who were classified as "Resigned or Cut Off," as shown in Exhibit 8. A reasonable conclusion is that, during the first 7 months of facility operation, about 169 individuals had either resigned or were terminated with employment periods of less than 7 months.

The regulatory requirement of a minimum of 250 workdays for SEC class eligibility was most likely not an arbitrary decision in terms of the time period. It is reasonable to assume that this time period was selected, because it represents a standard work-year consisting of 50 weeks and 5-day work weeks. Additionally, for workers whose exposure was either not monitored or whose records are incomplete/unavailable, regulators may have assumed that radiation exposures of less than 1 year were highly unlikely to have resulted in compensable organ doses under the Energy Employee Occupational Illness Compensation Program Act (EEOICPA).

These underlying assumptions/presumptions for the 250-workday criterion are not unreasonable, provided that there is sufficient assurance that radiation exposures (external and internal) to the worker were within radiation exposure limits as defined currently or in more recent years.

As summarized in Section 2 of this report, the operation of the Met Lab represented the very beginning of the nuclear era, and there was little information and few existing standards and methods for monitoring and protecting workers against the unprecedented radiological environments associated with the introduction of a nuclear reactor.

Section 3 of this report described the evolution of **tolerance levels** for external and internal exposures. These tolerance levels were based on limited historical data that had to be hurriedly supplemented by animal experiments and human clinical studies involving terminally ill patients. Moreover, tolerance levels were exclusively based on the dose-response relationships that govern radiation-induced deterministic (or nonstochastic) effects over relatively short time periods. Examples of determininstic effects that served as reference points for tolerance levels included skin erythema; alterations in blood-cell composition; cell death in select tissues/organs; changes in urine constituents; dermal changes, such as the loss of fingerprints; etc.

Exhibit 8. Metallurgical Project Personnel

(Source: Compton 1943)

[Exhibit 8 has been redacted in its entirety, due to Privacy Act concerns]

Not surprisingly, the limited knowledge and/or availability of data pertaining to **latent stochastic** health risks and the complex biokinetic behavior of internalized nuclides led to tolerance levels (as discussed in Section 4) that were scientifically flawed and inadequate for protecting the health of workers. When compared to present-day regulatory standards, tolerance levels for external doses, air concentrations, intakes by inhalation or ingestion, and sustained body burdens were many times higher. By far, the largest discrepancies between tolerance levels and present-day limits involved internal exposures to select radionuclides, as shown above in Tables 3, 4, 5, 6, and 7. In some instances, such **short-term/acute** exposures correspond to committed organ doses in the thousands of rems.

In the absence of available monitoring data for individual Met Lab workers, the extent to which doses of this magnitude occurred may be concluded on the basis of general, but site-specific, documentation and their interpretation. In Section 5, SC&A identifies documented instances of worker exposures in excess of tolerance levels, as well as radiological circumstances that must reasonably be assumed to have resulted in high exposures. Equally relevant to this report is that these high exposures were the result of either acute or short-term exposures (i.e., << 1 year duration). For example, positive fecal samples are likely the result of a **recent** inhalation exposure; similarly, significant changes in the cellularity of circulating blood commonly reflect substantial doses received over a relatively brief period of time.

At the time of facility operation at the Met Lab, our understanding of the dose-response of hemopoietic tissues to either acute or chronic radiation exposure was extremely limited, as acknowledged in a 1947 report entitled *Blood Changes in Humans Following Total Body Irradiation* (Nickson 1947):

> *A major problem facing the Manhattan Project was the protection of workers against damage resulting from either acute or chronic exposure to external radiation. It was anticipated that the* ***total dose*** *sustained by personnel and the* ***rate of administration*** *could* ***vary widely****. Further, there was the problem of assessing the damage, either transitory or permanent, which might arise from such exposures. The problem of detecting evidence of damage following exposure to total radiation* ***led to this study*** (Nickson 1947, pg. 1). [Emphasis added.]

In "this study," Nickson identified three groups (i.e., Group I, II, and III) of human subjects that were exposed to various doses of external radiation. Group I and Group II were patients with either non-curable cancer or other debilitating medical conditions who received doses up to several hundred rem.

Group III consisted of three normal adult volunteers from the Met Lab who were given a total dose of 21 R (with 7 R given on 3 consecutive days). Based on the same clinical criteria used to assess blood changes of other Met Lab workers, Nickson (1947) provided the following summary conclusions:

> *Group III.* ***No evidence of change in the cellular elements of the blood was noted in any of these cases****. It will be remembered that the individuals were all normal males insofar as could be demonstrated. These cases were of particular interest to use inasmuch as they indicated that acute exposure to* ***far more*** *than the maximum permissible level of 0.1 r per working day could not be expected to produce diagnostic changes in the elements of the peripheral blood which were studied.* [Emphasis added.]

Given the facts that (1) blood changes were noted among some Met Lab workers, and that (2) the 21 R dose received by Group III study subjects produced no evidence of change, suggest that acute doses well in excess of 21 R were not uncommon among Met Lab workers.

Just how high radiation doses may have been for Met Lab workers whose blood changes were considered significant may be estimated from other human data. Among the most relevant and best documented data are those involving workers exposed during the criticality accident in 1958 at the Y-12 facility. A brief summary of events and salient observations that are relevant to this report are presented below.

6.1 DESCRIPTION OF THE Y-12 ACCIDENT

The Y-12 accident occurred on June 16, 1958. An employee of the Union Carbide Nuclear Company was filling a 55-gallon drum with water in order to dissolve a residue of enriched uranium. Apparently, this is a normal procedure in the uranium-recovery operation, since the same operation had been done many times before by this particular employee. On this particular occasion, however, there was a sufficient amount of enriched uranium that as the water was added, a geometric configuration was reached that allowed the enriched uranium to reach criticality and the drum began to act as a reactor. As it reacted, the power level increased, the amount of heat produced increased, and the volume of water quickly began to “boil.” However, the boiling destroyed the necessary geometrical configuration for criticality. The reaction ceased, and it stopped boiling. As it cooled off, a critical conformation was again reached. The drum again went critical, causing it again to boil and to automatically shut itself off. This oscillation was repeated every few seconds. Both neutrons and gamma rays were produced and the fission products resulted in a continuous buildup of gamma-ray intensity. Since water was continuing to flow into the container, it soon diluted the material beyond that required for a critical configuration.

6.2 HEMATOLOGICAL FINDINGS IN BEHALF OF EIGHT WORKERS

At the time of the accident, two groups of workers were subject to intense clinical evaluation. By virtue of distance to the source, the first group consisted of five “highly exposed” workers identified as workers A, B, C, D, and E.

Highly Exposed Workers. Figure 3 shows that there is a rapid loss of lymphocytes from the peripheral blood that is the result of the direct killing of the highly sensitive mature and fully differentiated peripheral blood lymphocytes. Specifically, this dramatic drop from about 1,800 lymphocytes per mm^3 to about 1,100 per mm^3 occurred in the first few hours post-exposure. Other cellular changes involving white blood cells and platelets largely reflect damage to the immature hemopoietic stem cells of the bone marrow. Since injury to stem cells prevents the normal and continuous replacement of aged white blood cells, platelets, and red blood cells, the perturbations in peripheral blood cellularity have distinct timelines that for sublethal doses are most pronounced 4 to 8 weeks post-exposure.

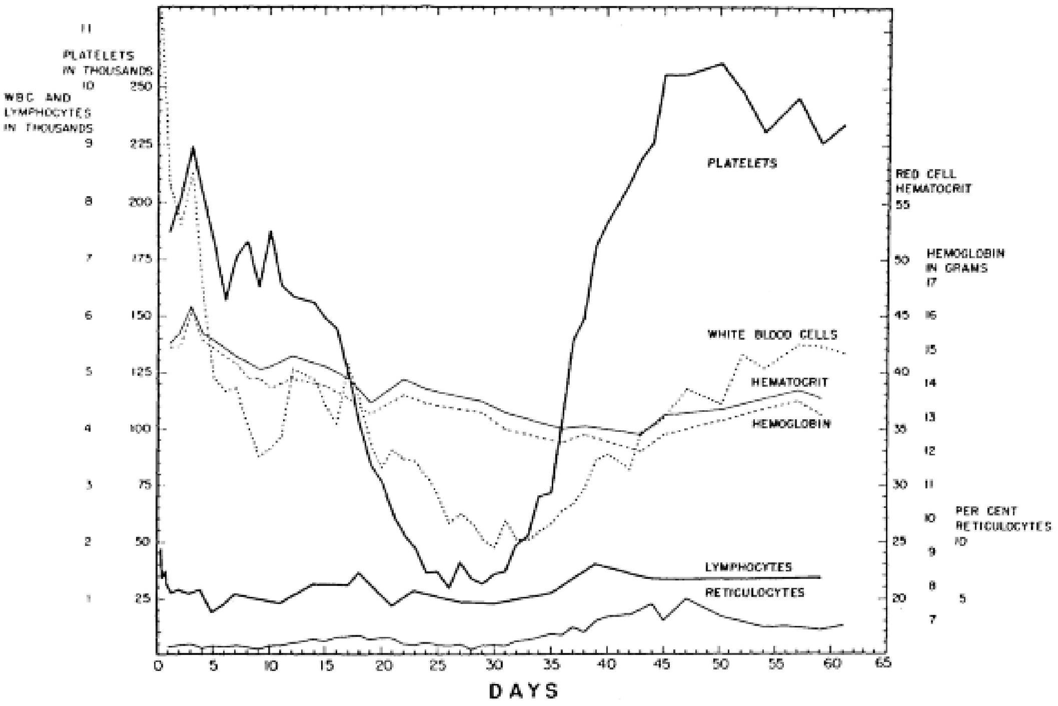


Figure 3. Hematologic Effects for Five Y-12 Workers A, B, C, D, and E
(Source: Andrews et al. 1961)

Lower Exposed Workers. In addition to the five highly exposed workers (who are not the focus of this discussion), there were also three other workers in the area at considerably greater distances. These lower exposed workers were identified as Workers F, G, and H.

As was the case for the five highly exposed individuals, Workers F, G, and H had pre-accident clinical baseline hematological data on file, which served as reference values for studying the impacts of their exposures. Results of the clinical investigation were summarized in the following statement (Sitterman 1959):

> ***The findings in these three low-dose patients can be summarized with the statement that there are no definite changes clearly attributable to radiation.*** [Emphasis added.]

This statement implies that in behalf of these three workers, no significant hematological changes were observed in spite of their exposures to substantial acute doses of photon and neutrons as discussed below.

6.3 ESTIMATES OF ACUTE DOSES TO THE LOWER-EXPOSED GROUP

For Workers F, G, and H, original estimates of the absorbed doses for photons and neutrons are given in Table 9.

Table 9. Original Doses Assigned to Workers F, G, and H
(Source: Sitterman 1959)

Worker	Dose (rads)		
	Photons	Neutrons	Total
F	50.5	18	68.5
G	50.5	18	68.5
H	16.8	6	22.8

Original doses, however, assumed a relative biological effectiveness (RBE) of 2 for the neutron component of the first collision absorbed dose based on **deterministic** effects relative to **lethality**.

Because Y-12 workers are eligible for compensation under EEOICPA, NIOSH reassessed the criticality doses in ORAUT-OTIB-0057, which was issued May 15, 2006 (ORAUT 2006). NIOSH's re-evaluation principally involved the substitution of the neutron RBE value of 2 for the deterministic lethality effect with the 1990 ICRP Publication 60 neutron weighting factors for stochastic effects applicable to cancer induction.

NIOSH's revised dose estimates for Workers F, G, and H, as given in Table 7-3 of ORAUT-OTIB-0057, are reproduced herein in Table 10.

Table 10. Dose Equivalent Estimates for Y-12 Workers F, G, and H

Worker	Dose (rads)		
	Neutrons	Photons	Total
F	242	55.6	297.6
G	242	55.6	297.6
H	79.7	18.5	98.2

In summary, whole-body single acute exposures of up to 300 rem dose equivalent were experienced by three Y-12 workers, but resulted in **no** discernable hematologic changes. Yet, hematological changes were noted among some Met Lab workers that were attributed to radiation exposure. In combination, these data, therefore, suggest that some Met Lab workers may have experienced doses ±300 rem delivered acutely or over short periods of time.

Important to note here is that evidence of hematological injury has been a topic of discussion among the Board's 250-day Work Group members.

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APPENDIX A – TRANSCRIPT OF ADVISORY BOARD MEETING HELD ON FEBRUARY 19, 2009

(Pages 55–62)

main thing is the Dow site. And we have been holding off on a meeting waiting -- hoping that [Identifying Information Redacted] would get his information finally. And Ted has been trying heroically, is it would fair to say, to try to resolve a whole bunch of issues, including some that apparently are new issues in regards to FACA and FOI that required some legal sleuthing, or whatever, review to decide how to do that.

I am hopeful, and I think Ted is hopeful, that those issues will get resolved. And I think we can try to schedule a meeting between now and the next Board meeting to -- work group meeting to discuss -- you know, further discuss the Dow site.

MR. KATZ: Thank you. Any questions?

(No response.)

Okay. Then, we have -- let's get the subcommittees at this point, but --

MEMBER MELIUS: Actually, the

Appendix A (Continued)

second part of that is the 250-day issue. I was waiting for Dr. Ziemer to come back. But we have one item there that I think is left over from the last meeting, which is the Metallurgical Laboratories that --

CHAIRMAN ZIEMER: Right. The issue at the Metallurgical Lab was the point that that work was a critical experiment. And there was some question on I think -- well, a number of those workers were there less than 250 days.

And I think there was a tentative conclusion last time -- and, Jim Neton, you may have to help me on this -- but there was some thought that that could be bounded, but it -- and it is not an incident in the sense of a -- it was not an uncontrolled critical event. It was a planned event. It was controlled.

But, nonetheless, there is the issue of a lot of these were less than 250 days. We are pretty confident there was not

Appendix A (Continued)

shielding. I think Dr. Poston confirmed that to us based on some historical information he had that there was primarily use of distance. And there is data on that experiment, but anyway that -- there is that issue for the Metallurgical Lab on 250 days.

I think perhaps the subcommittee was going to look at that. So we don't need to discuss it necessarily here, but --

MEMBER MELIUS: Do we need to task -- I think we need to task SC&A to look at it from a 250-day perspective. I think since they have not reviewed the site --

CHAIRMAN ZIEMER: Yes. Well, and this may be one of those things where -- and we want to make -- I don't know that there has been any attempt to bound that already. So I am not sure that we are there. You know, I am concerned about the issue of who does what first. There has not been an effort to do bounding.

MEMBER MELIUS: Well, the other --

Appendix A (Continued)

the other possibility is we have been dealing with the 250-day issue. Some of that we have been approaching and sort of tasking NIOSH. I don't know if that is a fair way of putting it.

CHAIRMAN ZIEMER: Asking. Asking and tasking.

MEMBER MELIUS: But looking at it as to whether these can be done through dose reconstruction, and that has some -- you know, we think it may actually be feasible -- for example, the Ames Laboratory to handle that -- those issues in that way. And Jim Neton is working on that portion of it.

And maybe rather than tasking is we hold a meeting of the SEC review group. Maybe we will just sort of look at Metallurgical Laboratories and see how that would fit in with the thing.

CHAIRMAN ZIEMER: The issue.

MEMBER MELIUS: The issue that we have looked at so far, and then decide whether

Appendix A (Continued)

-- you know, whether further work needs to be done on it and who should do that work. Is that --

CHAIRMAN ZIEMER: That is exactly in line with my thinking, Dr. Melius.

MEMBER MELIUS: Okay.

CHAIRMAN ZIEMER: I think a little more discussion needs to occur, because it's not clear to me how all of these pieces fit together -- the reactor versus the radiochemical operations that occur, which is why the class was added in the first place. And is there another class possibly there? So we need to talk through this.

DR. NETON: That's exactly what --

MEMBER MELIUS: I think it is just helpful to deal with the 250-day issue to have other examples to consider, because I think it is --

CHAIRMAN ZIEMER: Arjun would like to speak to some of this.

We got the line back here, and you

Appendix A (Continued)

probably know it because the buzzing has returned, I suppose. But in any event, we have a comment now from Arjun. And you may need to use this mic up here.

This is Dr. Makhijani coming to the mic.

DR. MAKHIJANI: Just a question, Dr. Melius. Did you want us to familiarize ourselves with the Met Lab question without any evaluation, so we can discuss? Or should we hold off until the meeting? I'm not clear on what we should do.

MEMBER MELIUS: I'm not sure either, but familiarize would probably be useful before the meeting. I'm not so sure whether that's a task -- familiarizing is a task or --

(Laughter.)

CHAIRMAN ZIEMER: Well, I think, as a minimum, if you look at the evaluation report for that petition, you will know what the issue is. And then, we will discuss --

Appendix A (Continued)

and you are sort of generally, you know -- I know you are familiar with the CP-1 program and the criticality experiment of Enrico Fermi and his colleagues.

DR. MAKHIJANI: Yes.

CHAIRMAN ZIEMER: So that's what we're talking about and many of those workers were there very briefly for that particular event and the preparation. And, of course, after that much of it moved to what is now Argonne National Lab. But some of those workers moved to other places.

DR. MAKHIJANI: Yes. So we will just look at it enough to know what NIOSH has done and prepare for a discussion.

CHAIRMAN ZIEMER: Right.

DR. MAKHIJANI: Thank you.

CHAIRMAN ZIEMER: And I guess that is sort of a tasking.

DR. MAKHIJANI: Yes.

CHAIRMAN ZIEMER: We are not asking you to -- you know, just read the documents

Appendix A (Continued)

and be familiar with what the discussion is going to be. Does that seem reasonable?

DR. MAKHIJANI: And it would be within the existing 250-day working group, so --

CHAIRMAN ZIEMER: Right.

DR. MAKHIJANI: I just needed clarification.

CHAIRMAN ZIEMER: Right. And you are already sort of tasked to work on the 250-day issue. So this is possibly one of those.

DR. MAKHIJANI: Yes.

MR. KATZ: Thank you.

We have Dr. Ziemer, TBD 6000, 6001.

CHAIRMAN ZIEMER: Right. Earlier this week we did task SC&A to begin review of the general steel industries, which is really the Appendix BB, but the petition portion of that, so that is underway.

The work group has not met since I last reported last month and identified a number of tasks that were underway. We do

APPENDIX B – MARCH 26, 2009, MEMO FROM DESIGNATED FEDERAL OFFICIAL

From: Katz, Ted (CDC/NIOSH/OD) [mailto:tmk1@cdc.gov]
Sent: Thursday, March 26, 2009 12:45 PM
To: Neton, Jim (CDC/NIOSH/OD); John Mauro
Cc: melius@nysliuna.org
Subject: Met Lab Follow-up

Jim Neton and John:

In going through some of the transcripts from Albuquerque I noted there was discussion of whether or not OCAS would be able to bound doses associated with the planned criticality and, by inference, if not, whether it would be considered a "discrete incident" defined by presence rather than exposure for a minimum of 250 work days. I don't think this is a live petition issue since Met Lab was an 83.14 defined around other exposures but the sense of the discussion was that OCAS might look into the question of bounding the related doses and SC&A was asked specifically to become familiar with the OCAS Evaluation Report and related materials to allow for a discussion of this as one of the case examples to be considered by the 250-day Board Work Group.

Just a reminder. The transcript for this issue, which was discussed on February 19th, should be up on the OCAS Web Site today or tomorrow.

--Ted