Region I 40-672

December 29, 1983

U. S. Nuclear Regulatory Commission
Material Licensing Branch
Division of Fuel Cycle and
Material Safety
Washington, D. C. 20555

Attention: Mr. John Hickey

Dear Mr. Hickey:

The purpose of this letter is to request an amendment of our specific Source Material License No. SMB-179. This amendment would incorporate an addition to our Scrap Packaging Procedures in accordance with the NRC's low-level waste Volume Reduction Policy. Furthermore, we are requesting authorization to conduct research and development for the reduction of low-level waste generated, and ultimately shipped to commercial waste disposal sites. These research and development efforts will entail both research conducted for volume reduction, and new product development. The following process description outlines an alternative waste consolidation method for the treatment of depleted uranium scrap.

Alternative Method for Processing Depleted Uranium Scrap

1. Background

Nuclear Metals, Inc. has traditionally inerted pyrophoric depleted uranium (* DU) scrap by encapsulating it in Portland cement. Experiments, testing and pilot operations have validated an alternative treatment method, involving the cleaning, drying and two-stage compaction of the turnings in a metal can. The product is a solid sheathed billet with a density of over 80% of cast uranium. Cross sectioning of billets reveals a solid surface, with little apparent macroscopic internal structure, that resists burning upon direct application of a flame. Randomly selected billets have been subjected to a D.O.T. accepted test for pyrophoricity and have been determined to be non-pyrophoric and shippable.

* "Depleted uranium" has been defined in 10 CFR 40.4 (o) as "the source material uranium in which the isotope uranium-235 is less than 0.711 weight percent of the total uranium present. Depleted uranium does not include special nuclear material".

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2229 Main Street, Concord, Massachusetts 01742 (617) 369-5410

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2. Description of Process

a. Pretreatment

Depleted uranium machine turnings (chips) are cleaned and dried prior to briquetting. This is accomplished primarily through displacement of surface moisture by a chlorinated or fluorochlorinated hydrocarbon (solvent). This process is supplemented as required by centrifuging and/or the application of a stream of forced air.

b. Briquetting

Pretreated chips are loaded into either a cylindrical or square die and compressed by a hydraulic press with a ram force of more than 150 tons. The product of this operation is a cylindrical or prismatic briquette (depending on the die used) approximately 1" to 1½" thick, weighing on the order of five to seven pounds, and having a density relative to cast uranium of at least 40%.

c. Consolidation

Briquettes are manually stacked in cylindrical or prismatic metal cans of compatible cross section with welded bottom cover plates. Top cover plates are placed on filled cans, which are then compacted by a hydraulic press with a ram force of more than 1,000 tons. Configuration of final billets is determined by die and can selection. A typical cylindrical billet approximately 8" long x 4½" O.D., would weigh about 70 pounds gross. Independent of size and shape, billets have a minimum density relative to cast uranium of 80% or more. Relative density of each compacted billet is determined from weighing and measurement of length. Following acceptance by the Compliance Department, billets are transported to the Packaging Area for storage to await packaging, final inspection and ultimate shipment to a licensed LLW facility.

3. Significance

When packaged for shallow land burial, volume reduction attained by consolidation of scrap over cement encapsulation at historically achieved loading densities is greater than 19:1. In addition there is a potential for licensed and controlled utilization of compacted billets as ballast weights in certain applications, which could divert significant amounts of D.U. from the waste stream and reduce the burden on limited LLW burial space.

In addition to the above scrap packaging alternative, we are requesting authorization to conduct research and development programs. These programs may involve new product development as well as research into low-level waste volume reduction.

We feel this amendment request is in keeping with the NRC's Volume Reduction Policy as stated in the December 14, 1981 letter from the NRC to all Material Licensees. Therefore, we are requesting that the NRC take expeditious action on this proposed license amendment, in line with the policy statement cited above.

Attached please find our Application Fee in the sum of Forty Dollars ($40.00).

If any additional information is necessary or if you would like to meet to discuss this matter further, please do not hesitate to contact us.

Sincerely,

Joseph Lischinsky
Regulatory Affairs Specialist
Health Physics Department

Attachment

JL/DAB/aj/cyc

NUCLEAR METALS INC.

January 15, 1984

Mr. Joseph C. Wang
U. S. Nuclear Regulatory Commission
Material Licensing Branch
Division of Fuel Cycle and
Material Safety
Washington, D. C. 20555

Re: Docket No. 40-00672

Gentlemen:

Enclosed for your review is correspondence relating to our Source Material License renewal (SMB-179). Based on a request from Region I and documented in a Confirmatory Action Letter (CAL No. 83-08) dated 5 August 1983, we hereby submit these programs for inclusion into our renewal request.

In reference to your letter dated November 9, 1983 which asks for additional information to support our renewal request, we believe that the three programs included herein partially fulfill your request. The balance of the information you need in order to take further action on our renewal request is being prepared and is expected to be forwarded to you by the end of January 1984.

Again, I want to thank you for your continued assistance during our Source Material License renewal process. If we can be of any help or if you have any questions concerning the enclosed, please do not hesitate to contact us.

Sincerely,

Frank J. Vumbaco

Frank J. Vumbaco, Manager
Health and Radiation Safety

FJV:aj

Enclosures ~~8403050156~~ 5pp.

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NMI INTERNAL EXPOSURE EVALUATION PROGRAM

As requested in the 5 August 1983 Confirmatory Action Letter's Item No. 6, a review of the elements of our Internal Evaluation Program is attached. The elements reviewed are as follows:

1). Metabolic Models for Uranium and Thorium

2). 10 CFR 20 MPC_a for Depleted Uranium and Thorium-234

3). NMI Air Sampling Program

4). NMI Urinalysis Program

5). NMI Annual Lung Counting Program

Program Summary

The primary method for determining compliance with 10 CFR 20.103 is the Air Sampling Program. Regardless of the solubility of Depleted Uranium (DU) or unsupported Th-234 (uncertain in some areas at this time), the Intake Method of tracking intakes using the most restrictive MPC_a values has the needed sensitivity for determining compliance with 10 CFR 20.103. Furthermore, the Intake Method is recommended in Regulatory Guide 8.30 and has been and is currently in use at NMI. Chronic and acute exposures to soluble DU lend themselves to further exposure control and diagnostic evaluations. The previously stated 50 µg/l investigation limit and 100 µg/l work restriction limit are still applicable. Chronic and acute exposures to insoluble DU or Th-234 lend themselves to further evaluation via annual lung counting. It should be noted that the lung burdens the metabolic models would predict are just not realized. Considering the above discussion, the Internal Exposure Evaluation Program is somewhat inflexible at this time. Acute intakes below or near the 40 MPC-hr limits for DU or Th-234 will be evaluated on a case by case basis by the Health Physics Department.

The following are projects currently underway that are aimed at increasing the program flexibility:

A). Simulated lung dissolution studies of DU and Th-234 aerosols by area for ICRP 30 inhalation classification.

B). Particle sizing to determine AMAD by area for adjustment of the ICRP 30 Lung Model.

C). In-house lung counting for Th-234 and possibly DU.

D). Urinalysis for unsupported Th-234 based upon metabolic model and a potassium (i.e., K-40) precipitation using sodium cobalt nitrite in order to reduce background.

METABOLIC MODELS FOR URANIUM AND THORIUM

General Review

The evaluation of bioassay data requires an analytical approach in the interpretation of results. The current 10 CFR 20 limits on intake of radionuclides are based upon the 1959 ICRP Committee 2 Report. The respective models used do not easily allow evaluations of intake based on bioassay data. With this in mind, and precedent existing (see NRC Regulatory Guide 8.9) for the use of more current ICRP models, various exposure scenarios have been examined using the 1979 Committee 2 ICRP Publication 30 models. The lung model, GI model, and retention functions recommended in this publication have been used to generate the attached data. A summary of the metabolic data is below.

Uranium

a) Uptake to Blood

f_1 (soluble U) = 0.05

f_1 (insoluble U) = 0.002

b) Inhalation Class

Compound	Class	f_1
UF_6, UO_2F_2, $UO_2(NO_3)_2$	D	0.05
UO_3, UF_4, UCl_4	W	0.05
UO_2, U_3O_8	Y	0.002

c) Distribution and Retention

$$R_s(t) = \sum_{i=1}^{7} C_{iS} \exp(-\alpha_i t)$$

Where,

$C_{1S} = 0.20$	$\alpha_1 = \ln 2/20d$	Bone
$C_{2S} = 0.023$	$\alpha_2 = \ln 2/5000d$	Bone
$C_{3S} = 0.12$	$\alpha_3 = \ln 2/6d$	Kidney
$C_{4S} = 0.00052$	$\alpha_4 = \ln 2/1500d$	Kidney
$C_{5S} = 0.12$	$\alpha_5 = \ln 2/6d$	All Other Tissues
$C_{6S} = 0.00052$	$\alpha_6 = \ln 2/1500d$	All Other Tissues
$C_{7S} = 0.53596$	$\alpha_7 = \ln 2/0.25d$	Excretion

d) Additional Data

F_u = 1.0 (ICRP 10)

AMAD = 1 µm (ICRP 30 and attached results from DU grinding operations)

Thorium

a) Uptake to Blood

f_1 (All Compounds) = 2×10^{-4}

b) Inhalation Class

Compound	Class	f_1
Oxides & Hydroxides	Y	2×10^{-4}
All Others	W	2×10^{-4}

c) Distribution and Retention

$$R_s(t) = \sum_{i=1}^{4} C_{is} \exp(-\alpha_i t)$$

Where, C_{1S} = 0.70 ; α_1 = ln 2/8000d   Bone

C_{2S} = 0.04 ; α_2 = ln 2/700d   Liver

C_{3S} = 0.16 ; α_3 = ln 2/700d   All Other Tissues

C_{4S} = 0.10 ; α_4 = ln 2/0.5d   Excretion

d) Additional Data

F_u = 0.9 (Conservative value; ICRP 10A recommends F_u = 1.0, F_f = 0.01)

AMAD = 1 µm (ICRP 30)

URANIUM 238
CHRONIC INHALATION INTAKE 1.000E+00 mg /DAY
100.0% CLASS Y 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 2.000E-03

SYSTEMIC RETENTION EQUATION PARAMETERS

COMPARTMENT	COEFFICIENT	HALFLIFE(DAYS)
1	5.360E-01	2.500E-01
2	2.400E-01	6.000E+00
3	2.000E-01	2.000E+01
4	1.040E-03	1.500E+03
5	2.300E-02	5.000E+03

FRACTION EXCRETED IN URINE(FU)= 1.000E+00 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 1.650E+12 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS
CHRONIC INTAKE PERIOD= 2.000E+02 DAYS

DAYS POST INTAKE	NASAL BURDEN mg	LYMPH BURDEN mg	LUNG BURDEN mg	GI BURDEN mg	SYSTEMIC BURDEN mg	TOTAL BURDEN mg	ACCUMULATED FECES mg	ACCUMULATED URINE mg	INCREMENTAL URINE mg	INSTANTANEOUS URINE mg /L
10.00	1.714E-01	2.582E-03	1.688E+00	8.328E-01	1.696E-02	2.538E+00	3.560E+00	3.045E-02	3.666E-03	2.647E-03
20.00	1.714E-01	1.026E-02	3.166E+00	8.361E-01	2.682E-02	4.029E+00	8.329E+00	7.077E-02	4.279E-03	3.072E-03
30.00	1.714E-01	2.293E-02	4.628E+00	8.385E-01	3.377E-02	5.500E+00	1.311E+01	1.158E-01	4.661E-03	3.341E-03
40.00	1.714E-01	4.049E-02	6.075E+00	8.408E-01	3.925E-02	6.955E+00	1.791E+01	1.640E-01	4.951E-03	3.546E-03
50.00	1.714E-01	6.285E-02	7.507E+00	8.431E-01	4.388E-02	8.394E+00	2.272E+01	2.149E-01	5.198E-03	3.721E-03
60.00	1.714E-01	8.990E-02	8.924E+00	8.453E-01	4.799E-02	9.817E+00	2.754E+01	2.681E-01	5.421E-03	3.879E-03
70.00	1.714E-01	1.216E-01	1.033E+01	8.475E-01	5.175E-02	1.123E+01	3.238E+01	3.235E-01	5.630E-03	4.028E-03
80.00	1.714E-01	1.577E-01	1.172E+01	8.497E-01	5.529E-02	1.262E+01	3.723E+01	3.809E-01	5.829E-03	4.170E-03
90.00	1.714E-01	1.983E-01	1.309E+01	8.519E-01	5.868E-02	1.400E+01	4.209E+01	4.402E-01	6.022E-03	4.308E-03
100.00	1.714E-01	2.432E-01	1.445E+01	8.540E-01	6.199E-02	1.537E+01	4.696E+01	5.015E-01	6.211E-03	4.443E-03
110.00	1.714E-01	2.923E-01	1.580E+01	8.561E-01	6.525E-02	1.672E+01	5.185E+01	5.646E-01	6.397E-03	4.576E-03
120.00	1.714E-01	3.456E-01	1.713E+01	8.582E-01	6.849E-02	1.806E+01	5.674E+01	6.296E-01	6.581E-03	4.707E-03
130.00	1.714E-01	4.029E-01	1.845E+01	8.602E-01	7.173E-02	1.938E+01	6.165E+01	6.964E-01	6.765E-03	4.838E-03
140.00	1.714E-01	4.642E-01	1.975E+01	8.622E-01	7.498E-02	2.069E+01	6.657E+01	7.650E-01	6.947E-03	4.968E-03
150.00	1.714E-01	5.294E-01	2.105E+01	8.642E-01	7.825E-02	2.199E+01	7.151E+01	8.355E-01	7.129E-03	5.098E-03
160.00	1.714E-01	5.984E-01	2.232E+01	8.662E-01	8.155E-02	2.327E+01	7.645E+01	9.078E-01	7.310E-03	5.228E-03
170.00	1.714E-01	6.712E-01	2.359E+01	8.681E-01	8.489E-02	2.454E+01	8.140E+01	9.819E-01	7.492E-03	5.358E-03
180.00	1.714E-01	7.475E-01	2.484E+01	8.700E-01	8.826E-02	2.580E+01	8.637E+01	1.058E+00	7.674E-03	5.487E-03
190.00	1.714E-01	8.275E-01	2.609E+01	8.719E-01	9.167E-02	2.705E+01	9.134E+01	1.136E+00	7.856E-03	5.617E-03
200.00	1.714E-01	9.109E-01	2.731E+01	8.737E-01	9.512E-02	2.828E+01	9.633E+01	1.215E+00	8.038E-03	5.747E-03
210.00	5.108E-09	9.952E-01	2.684E+01	4.275E-02	8.164E-02	2.697E+01	9.777E+01	1.266E+00	4.554E-03	3.230E-03
220.00	1.522E-16	1.078E+00	2.657E+01	4.122E-02	7.532E-02	2.668E+01	9.801E+01	1.309E+00	4.123E-03	2.935E-03
230.00	4.537E-24	1.158E+00	2.630E+01	4.066E-02	7.194E-02	2.641E+01	9.824E+01	1.349E+00	3.923E-03	2.797E-03
240.00	1.352E-31	1.238E+00	2.603E+01	4.010E-02	7.008E-02	2.614E+01	9.847E+01	1.387E+00	3.816E-03	2.723E-03
250.00	0.000E+00	1.315E+00	2.577E+01	3.954E-02	6.911E-02	2.588E+01	9.870E+01	1.425E+00	3.752E-03	2.678E-03
260.00	0.000E+00	1.391E+00	2.551E+01	3.900E-02	6.871E-02	2.561E+01	9.892E+01	1.463E+00	3.712E-03	2.650E-03
270.00	0.000E+00	1.465E+00	2.525E+01	3.846E-02	6.869E-02	2.536E+01	9.914E+01	1.500E+00	3.686E-03	2.632E-03
280.00	0.000E+00	1.537E+00	2.499E+01	3.793E-02	6.894E-02	2.510E+01	9.936E+01	1.536E+00	3.670E-03	2.621E-03
290.00	0.000E+00	1.608E+00	2.474E+01	3.741E-02	6.938E-02	2.485E+01	9.958E+01	1.573E+00	3.660E-03	2.614E-03
300.00	0.000E+00	1.678E+00	2.449E+01	3.690E-02	6.994E-02	2.460E+01	9.979E+01	1.609E+00	3.654E-03	2.610E-03

URANIUM 238
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3	2.000E-01	2.000E+01
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FRACTION EXCRETED IN URINE(FU)= 1.000E+00 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
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10.00	1.562E-01	7.904E-03	1.597E+00	7.000E-01	3.269E-01	2.624E+00	2.935E+00	5.842E-01	7.111E-02	5.140E-02
20.00	1.562E-01	2.887E-02	2.041E+00	7.201E-01	5.241E-01	4.085E+00	6.985E+00	1.374E+00	8.430E-02	6.058E-02
30.00	1.562E-01	5.939E-02	3.936E+00	7.367E-01	6.668E-01	5.339E+00	1.114E+01	2.266E+00	9.283E-02	6.656E-02
40.00	1.562E-01	9.663E-02	4.900E+00	7.513E-01	7.808E-01	6.432E+00	1.538E+01	3.231E+00	9.924E-02	7.109E-02
50.00	1.562E-01	1.383E-01	5.748E+00	7.639E-01	8.769E-01	7.389E+00	1.970E+01	4.253E+00	1.045E-01	7.480E-02
60.00	1.562E-01	1.827E-01	6.495E+00	7.749E-01	9.608E-01	8.230E+00	2.409E+01	5.322E+00	1.089E-01	7.794E-02
70.00	1.562E-01	2.284E-01	7.152E+00	7.845E-01	1.036E+00	8.972E+00	2.854E+01	6.433E+00	1.127E-01	8.066E-02
80.00	1.562E-01	2.744E-01	7.730E+00	7.928E-01	1.104E+00	9.627E+00	3.304E+01	7.579E+00	1.161E-01	8.303E-02
90.00	1.562E-01	3.197E-01	8.238E+00	8.001E-01	1.167E+00	1.021E+01	3.758E+01	8.757E+00	1.190E-01	8.511E-02
100.00	1.562E-01	3.638E-01	8.686E+00	8.064E-01	1.226E+00	1.072E+01	4.216E+01	9.961E+00	1.216E-01	8.695E-02
110.00	1.562E-01	4.062E-01	9.079E+00	8.119E-01	1.281E+00	1.117E+01	4.678E+01	1.119E+01	1.239E-01	8.857E-02
120.00	1.562E-01	4.467E-01	9.425E+00	8.167E-01	1.333E+00	1.158E+01	5.143E+01	1.244E+01	1.259E-01	9.001E-02
130.00	1.562E-01	4.849E-01	9.730E+00	8.209E-01	1.383E+00	1.193E+01	5.610E+01	1.371E+01	1.277E-01	9.129E-02
140.00	1.562E-01	5.209E-01	9.997E+00	8.245E-01	1.431E+00	1.225E+01	6.079E+01	1.500E+01	1.293E-01	9.242E-02
150.00	1.562E-01	5.546E-01	1.023E+01	8.277E-01	1.478E+00	1.254E+01	6.551E+01	1.630E+01	1.307E-01	9.343E-02
160.00	1.562E-01	5.859E-01	1.044E+01	8.304E-01	1.523E+00	1.279E+01	7.024E+01	1.761E+01	1.320E-01	9.433E-02
170.00	1.562E-01	6.150E-01	1.062E+01	8.328E-01	1.566E+00	1.302E+01	7.499E+01	1.894E+01	1.331E-01	9.513E-02
180.00	1.562E-01	6.418E-01	1.078E+01	8.349E-01	1.609E+00	1.323E+01	7.974E+01	2.027E+01	1.341E-01	9.585E-02
190.00	1.562E-01	6.664E-01	1.092E+01	8.367E-01	1.651E+00	1.341E+01	8.451E+01	2.162E+01	1.350E-01	9.648E-02
200.00	1.562E-01	6.891E-01	1.105E+01	8.383E-01	1.691E+00	1.357E+01	8.929E+01	2.298E+01	1.358E-01	9.705E-02
210.00	4.644E-09	7.019E-01	9.557E+00	1.397E-01	1.404E+00	1.110E+01	9.115E+01	2.375E+01	6.543E-02	4.615E-02
220.00	1.384E-16	6.998E-01	8.408E+00	1.208E-01	1.246E+00	9.775E+00	9.189E+01	2.433E+01	5.287E-02	3.742E-02
230.00	4.124E-24	6.866E-01	7.397E+00	1.052E-01	1.142E+00	8.644E+00	9.254E+01	2.482E+01	4.491E-02	3.184E-02
240.00	1.229E-31	6.650E-01	6.507E+00	9.157E-02	1.066E+00	7.665E+00	9.310E+01	2.523E+01	3.899E-02	2.766E-02
250.00	0.000E+00	6.375E-01	5.723E+00	7.971E-02	1.008E+00	6.810E+00	9.360E+01	2.559E+01	3.420E-02	2.427E-02
260.00	0.000E+00	6.060E-01	5.033E+00	6.939E-02	9.608E-01	6.063E+00	9.402E+01	2.591E+01	3.016E-02	2.141E-02
270.00	0.000E+00	5.720E-01	4.426E+00	6.041E-02	9.225E-01	5.409E+00	9.440E+01	2.620E+01	2.668E-02	1.894E-02
280.00	0.000E+00	5.366E-01	3.892E+00	5.259E-02	8.906E-01	4.835E+00	9.472E+01	2.645E+01	2.365E-02	1.680E-02
290.00	0.000E+00	5.008E-01	3.422E+00	4.578E-02	8.636E-01	4.331E+00	9.500E+01	2.667E+01	2.100E-02	1.491E-02
300.00	0.000E+00	4.652E-01	3.008E+00	3.986E-02	8.406E-01	3.888E+00	9.525E+01	2.686E+01	1.866E-02	1.325E-02

URANIUM 238
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1	5.360E-01	2.500E-01
2	2.400E-01	6.000E+00
3	2.000E-01	2.000E+01
4	1.040E-03	1.500E+03
5	2.300E-02	5.000E+03

FRACTION EXCRETED IN URINE(FU)= 1.000E+00 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 1.650E+12 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS
CHRONIC INTAKE PERIOD= 2.000E+02 DAYS

DAYS POST INTAKE	NASAL BURDEN mg	LYMPH BURDEN mg	LUNG BURDEN mg	GI BURDEN mg	SYSTEMIC BURDEN mg	TOTAL BURDEN mg	ACCUMULATED FECES mg	ACCUMULATED URINE mg	INCREMENTAL URINE mg	INSTANTANEOUS URINE mg /L
10.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	1.660E+00	2.135E+00	1.205E+00	2.956E+00	3.603E-01	2.599E-01
20.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	2.593E+00	3.068E+00	2.668E+00	6.860E+00	4.092E-01	2.934E-01
30.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	3.196E+00	3.671E+00	4.131E+00	1.109E+01	4.327E-01	3.097E-01
40.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	3.628E+00	4.103E+00	5.594E+00	1.550E+01	4.459E-01	3.188E-01
50.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	3.959E+00	4.434E+00	7.057E+00	2.000E+01	4.541E-01	3.246E-01
60.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	4.223E+00	4.698E+00	8.520E+00	2.458E+01	4.595E-01	3.284E-01
70.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	4.443E+00	4.918E+00	9.983E+00	2.919E+01	4.633E-01	3.310E-01
80.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	4.632E+00	5.107E+00	1.145E+01	3.384E+01	4.660E-01	3.329E-01
90.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	4.798E+00	5.273E+00	1.291E+01	3.851E+01	4.678E-01	3.342E-01
100.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	4.950E+00	5.425E+00	1.437E+01	4.320E+01	4.691E-01	3.351E-01
110.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	5.090E+00	5.565E+00	1.584E+01	4.790E+01	4.701E-01	3.358E-01
120.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	5.223E+00	5.698E+00	1.730E+01	5.260E+01	4.707E-01	3.362E-01
130.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	5.350E+00	5.825E+00	1.876E+01	5.731E+01	4.712E-01	3.366E-01
140.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	5.473E+00	5.948E+00	2.022E+01	6.202E+01	4.715E-01	3.368E-01
150.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	5.593E+00	6.068E+00	2.169E+01	6.674E+01	4.718E-01	3.370E-01
160.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	5.711E+00	6.186E+00	2.315E+01	7.146E+01	4.720E-01	3.371E-01
170.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	5.828E+00	6.303E+00	2.461E+01	7.618E+01	4.721E-01	3.372E-01
180.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	5.944E+00	6.419E+00	2.608E+01	8.090E+01	4.722E-01	3.373E-01
190.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	6.058E+00	6.533E+00	2.754E+01	8.562E+01	4.723E-01	3.373E-01
200.00	4.328E-03	3.607E-02	2.187E-01	2.563E-01	6.172E+00	6.647E+00	2.900E+01	9.035E+01	4.723E-01	3.374E-01
210.00	0.000E+00	5.112E-07	6.832E-07	1.041E-05	4.626E+00	4.626E+00	2.926E+01	9.211E+01	1.120E-01	7.750E-02
220.00	0.000E+00	9.423E-13	1.106E-12	8.359E-10	3.806E+00	3.806E+00	2.926E+01	9.293E+01	6.324E-02	4.404E-02
230.00	0.000E+00	1.332E-18	1.489E-18	3.795E-14	3.316E+00	3.316E+00	2.926E+01	9.342E+01	3.975E-02	2.780E-02
240.00	0.000E+00	1.684E-24	1.833E-24	1.723E-18	2.996E+00	2.996E+00	2.926E+01	9.374E+01	2.661E-02	1.865E-02
250.00	0.000E+00	2.001E-30	2.143E-30	7.822E-23	2.778E+00	2.778E+00	2.926E+01	9.396E+01	1.842E-02	1.292E-02
260.00	0.000E+00	0.000E+00	0.000E+00	3.551E-27	2.625E+00	2.625E+00	2.926E+01	9.411E+01	1.297E-02	9.102E-03
270.00	0.000E+00	0.000E+00	0.000E+00	1.612E-31	2.517E+00	2.517E+00	2.926E+01	9.422E+01	9.218E-03	6.474E-03
280.00	0.000E+00	0.000E+00	0.000E+00	7.059E-36	2.440E+00	2.440E+00	2.926E+01	9.430E+01	6.603E-03	4.639E-03
290.00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.385E+00	2.385E+00	2.926E+01	9.436E+01	4.764E-03	3.348E-03
300.00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	2.345E+00	2.345E+00	2.926E+01	9.440E+01	3.467E-03	2.438E-03

URANIUM 238
CHRONIC INHALATION INTAKE 1.000E+00 mg /DAY
56.0% CLASS D 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 5.000E-02
44.0% CLASS Y 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 2,000E-03

SYSTEMIC RETENTION EQUATION PARAMETERS

COMPARTMENT	COEFFICIENT	HALFLIFE(DAYS)
1	5.360E-01	2.500E-01
2	2.400E-01	6.000E+00
3	2.000E-01	2.000E+01
4	1.040E-03	1.500E+03
5	2.300E-02	5.000E+03

FRACTION EXCRETED IN URINE(FU)= 1.000E+00 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 1.650E+12 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS
CHRONIC INTAKE PERIOD= 2.000E+02 DAYS

DAYS POST INTAKE	NASAL BURDEN mg	LYMPH BURDEN mg	LUNG BURDEN mg	GI BURDEN mg	SYSTEMIC BURDEN mg	TOTAL BURDEN mg	ACCUMULATED FECES mg	ACCUMULATED URINE mg	INCREMENTAL URINE mg	INSTANTANEOUS URINE mg /L
10.00	7.786E-02	2.133E-02	8.654E-01	5.100E-01	9.368E-01	2.312E+00	2.241E+00	1.669E+00	2.034E-01	1.467E-01
20.00	7.786E-02	2.471E-02	1.515E+00	5.115E-01	1.464E+00	3.491E+00	5.159E+00	3.873E+00	2.310E-01	1.657E-01
30.00	7.786E-02	3.029E-02	2.159E+00	5.125E-01	1.805E+00	4.476E+00	8.083E+00	6.263E+00	2.444E-01	1.749E-01
40.00	7.786E-02	3.801E-02	2.795E+00	5.135E-01	2.049E+00	5.358E+00	1.101E+01	8.751E+00	2.519E-01	1.801E-01
50.00	7.786E-02	4.785E-02	3.425E+00	5.145E-01	2.236E+00	6.176E+00	1.395E+01	1.130E+01	2.566E-01	1.834E-01
60.00	7.786E-02	5.975E-02	4.049E+00	5.155E-01	2.386E+00	6.951E+00	1.689E+01	1.388E+01	2.597E-01	1.856E-01
70.00	7.786E-02	7.368E-02	4.666E+00	5.165E-01	2.511E+00	7.694E+00	1.984E+01	1.649E+01	2.619E-01	1.872E-01
80.00	7.786E-02	8.959E-02	5.277E+00	5.174E-01	2.618E+00	8.413E+00	2.279E+01	1.912E+01	2.635E-01	1.883E-01
90.00	7.786E-02	1.074E-01	5.882E+00	5.184E-01	2.713E+00	9.113E+00	2.575E+01	2.176E+01	2.646E-01	1.890E-01
100.00	7.786E-02	1.272E-01	6.480E+00	5.193E-01	2.799E+00	9.799E+00	2.871E+01	2.441E+01	2.654E-01	1.896E-01
110.00	7.786E-02	1.488E-01	7.073E+00	5.202E-01	2.879E+00	1.047E+01	3.168E+01	2.707E+01	2.660E-01	1.900E-01
120.00	7.786E-02	1.723E-01	7.659E+00	5.212E-01	2.955E+00	1.114E+01	3.465E+01	2.973E+01	2.665E-01	1.904E-01
130.00	7.786E-02	1.975E-01	8.239E+00	5.220E-01	3.028E+00	1.179E+01	3.763E+01	3.240E+01	2.668E-01	1.906E-01
140.00	7.786E-02	2.245E-01	8.814E+00	5.229E-01	3.098E+00	1.243E+01	4.062E+01	3.507E+01	2.671E-01	1.908E-01
150.00	7.786E-02	2.532E-01	9.382E+00	5.238E-01	3.167E+00	1.307E+01	4.361E+01	3.774E+01	2.673E-01	1.910E-01
160.00	7.786E-02	2.835E-01	9.945E+00	5.247E-01	3.234E+00	1.370E+01	4.660E+01	4.042E+01	2.675E-01	1.911E-01
170.00	7.786E-02	3.155E-01	1.050E+01	5.255E-01	3.301E+00	1.433E+01	4.960E+01	4.309E+01	2.677E-01	1.912E-01
180.00	7.786E-02	3.491E-01	1.105E+01	5.264E-01	3.367E+00	1.495E+01	5.260E+01	4.577E+01	2.678E-01	1.913E-01
190.00	7.786E-02	3.843E-01	1.160E+01	5.272E-01	3.433E+00	1.556E+01	5.561E+01	4.845E+01	2.679E-01	1.914E-01
200.00	7.786E-02	4.210E-01	1.214E+01	5.280E-01	3.498E+00	1.617E+01	5.863E+01	5.113E+01	2.680E-01	1.915E-01
210.00	2.247E-09	4.379E-01	1.181E+01	1.882E-02	2.627E+00	1.446E+01	5.940E+01	5.214E+01	6.475E-02	4.482E-02
220.00	6.698E-17	4.742E-01	1.169E+01	1.814E-02	2.165E+00	1.387E+01	5.951E+01	5.262E+01	3.723E-02	2.595E-02
230.00	1.996E-24	5.097E-01	1.157E+01	1.789E-02	1.888E+00	1.348E+01	5.961E+01	5.291E+01	2.399E-02	1.680E-02
240.00	5.949E-32	5.445E-01	1.145E+01	1.764E-02	1.708E+00	1.318E+01	5.971E+01	5.311E+01	1.658E-02	1.164E-02
250.00	0.000E+00	5.786E-01	1.134E+01	1.740E-02	1.586E+00	1.294E+01	5.981E+01	5.325E+01	1.196E-02	8.414E-03
260.00	0.000E+00	6.119E-01	1.122E+01	1.716E-02	1.500E+00	1.274E+01	5.991E+01	5.335E+01	8.894E-03	6.263E-03
270.00	0.000E+00	6.445E-01	1.111E+01	1.692E-02	1.440E+00	1.257E+01	6.001E+01	5.342E+01	6.784E-03	4.784E-03
280.00	0.000E+00	6.764E-01	1.100E+01	1.669E-02	1.397E+00	1.241E+01	6.011E+01	5.348E+01	5.312E-03	3.751E-03
290.00	0.000E+00	7.077E-01	1.089E+01	1.646E-02	1.366E+00	1.227E+01	6.020E+01	5.353E+01	4.278E-03	3.025E-03
300.00	0.000E+00	7.382E-01	1.078E+01	1.623E-02	1.344E+00	1.214E+01	6.029E+01	5.357E+01	3.549E-03	2.514E-03

URANIUM 238
ACUTE INHALATION INTAKE 1.000E+00 mg
100.0% CLASS Y 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 2.000E-03

SYSTEMIC RETENTION EQUATION PARAMETERS

COMPARTMENT	COEFFICIENT	HALFLIFE(DAYS)
1	5.360E-01	2.500E-01
2	2.400E-01	6.000E+00
3	2.000E-01	2.000E+01
4	1.040E-03	1.500E+03
5	2.300E-02	5.000E+03

FRACTION EXCRETED IN URINE(FU)= 1.000E+00 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 1.650E+12 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS

DAYS POST INTAKE	NASAL BURDEN mg	LYMPH BURDEN mg	LUNG BURDEN mg	GI BURDEN mg	SYSTEMIC BURDEN mg	TOTAL BURDEN mg	ACCUMULATED FECES mg	ACCUMULATED URINE mg	INCREMENTAL URINE mg	INSTANTANEOUS URINE mg /L
1.00	5.250E-02	5.193E-05	2.141E-01	3.081E-01	2.176E-03	5.243E-01	5.089E-02	2.281E-03	2.281E-03	5.816E-04
2.00	9.281E-03	1.038E-04	1.810E-01	2.271E-01	1.947E-03	4.101E-01	2.077E-01	2.739E-03	4.579E-04	1.092E-04
3.00	1.641E-03	1.555E-04	1.652E-01	1.225E-01	1.821E-03	2.895E-01	3.359E-01	2.943E-03	2.041E-04	1.188E-04
4.00	2.900E-04	2.071E-04	1.572E-01	5.967E-02	1.712E-03	2.186E-01	4.080E-01	3.092E-03	1.491E-04	9.721E-05
5.00	5.127E-05	2.586E-04	1.532E-01	2.817E-02	1.611E-03	1.829E-01	4.438E-01	3.220E-03	1.276E-04	8.590E-05
6.00	9.064E-06	3.100E-04	1.511E-01	1.330E-02	1.519E-03	1.659E-01	4.608E-01	3.334E-03	1.144E-04	7.786E-05
7.00	1.602E-06	3.614E-04	1.499E-01	6.382E-03	1.435E-03	1.577E-01	4.688E-01	3.438E-03	1.043E-04	7.139E-05
8.00	2.832E-07	4.126E-04	1.493E-01	3.159E-03	1.358E-03	1.538E-01	4.727E-01	3.534E-03	9.601E-05	6.590E-05
9.00	5.007E-08	4.637E-04	1.489E-01	1.641E-03	1.287E-03	1.518E-01	4.746E-01	3.623E-03	8.884E-05	6.112E-05
10.00	8.851E-09	5.147E-04	1.486E-01	9.186E-04	1.223E-03	1.508E-01	4.755E-01	3.706E-03	8.255E-05	5.689E-05
11.00	1.565E-09	5.656E-04	1.484E-01	5.706E-04	1.163E-03	1.501E-01	4.761E-01	3.783E-03	7.696E-05	5.312E-05
12.00	2.766E-10	6.164E-04	1.482E-01	4.015E-04	1.109E-03	1.497E-01	4.764E-01	3.855E-03	7.196E-05	4.974E-05
13.00	4.890E-11	6.670E-04	1.480E-01	3.186E-04	1.060E-03	1.494E-01	4.767E-01	3.922E-03	6.748E-05	4.671E-05
14.00	8.644E-12	7.176E-04	1.479E-01	2.777E-04	1.014E-03	1.492E-01	4.768E-01	3.986E-03	6.344E-05	4.397E-05
15.00	1.528E-12	7.681E-04	1.477E-01	2.574E-04	9.718E-04	1.490E-01	4.770E-01	4.045E-03	5.980E-05	4.150E-05
16.00	2.701E-13	8.185E-04	1.476E-01	2.471E-04	9.330E-04	1.487E-01	4.771E-01	4.102E-03	5.651E-05	3.927E-05
17.00	4.775E-14	8.688E-04	1.474E-01	2.419E-04	8.972E-04	1.486E-01	4.773E-01	4.156E-03	5.354E-05	3.725E-05
18.00	8.441E-15	9.190E-04	1.473E-01	2.391E-04	8.641E-04	1.484E-01	4.774E-01	4.206E-03	5.084E-05	3.542E-05
19.00	1.492E-15	9.691E-04	1.471E-01	2.376E-04	8.334E-04	1.482E-01	4.776E-01	4.255E-03	4.840E-05	3.376E-05
20.00	2.638E-16	1.019E-03	1.470E-01	2.366E-04	8.050E-04	1.480E-01	4.777E-01	4.301E-03	4.619E-05	3.225E-05
21.00	4.663E-17	1.069E-03	1.468E-01	2.360E-04	7.786E-04	1.478E-01	4.778E-01	4.345E-03	4.418E-05	3.088E-05
22.00	8.243E-18	1.119E-03	1.467E-01	2.355E-04	7.540E-04	1.476E-01	4.780E-01	4.387E-03	4.235E-05	2.963E-05
23.00	1.457E-18	1.168E-03	1.465E-01	2.351E-04	7.311E-04	1.475E-01	4.781E-01	4.428E-03	4.068E-05	2.850E-05
24.00	2.576E-19	1.218E-03	1.463E-01	2.347E-04	7.097E-04	1.473E-01	4.782E-01	4.467E-03	3.916E-05	2.746E-05
25.00	4.554E-20	1.267E-03	1.462E-01	2.344E-04	6.897E-04	1.471E-01	4.784E-01	4.505E-03	3.777E-05	2.651E-05
26.00	8.050E-21	1.317E-03	1.460E-01	2.341E-04	6.710E-04	1.470E-01	4.785E-01	4.542E-03	3.650E-05	2.565E-05
27.00	1.423E-21	1.366E-03	1.459E-01	2.337E-04	6.535E-04	1.468E-01	4.786E-01	4.577E-03	3.534E-05	2.485E-05
28.00	2.516E-22	1.415E-03	1.457E-01	2.334E-04	6.371E-04	1.466E-01	4.788E-01	4.611E-03	3.427E-05	2.412E-05
29.00	4.447E-23	1.464E-03	1.456E-01	2.331E-04	6.216E-04	1.464E-01	4.789E-01	4.644E-03	3.329E-05	2.345E-05
30.00	7.862E-24	1.513E-03	1.454E-01	2.328E-04	6.070E-04	1.463E-01	4.790E-01	4.677E-03	3.239E-05	2.283E-05

URANIUM 238
ACUTE INHALATION INTAKE 1.000E+00 mg
100.0% CLASS W 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 5.000E-02

SYSTEMIC RETENTION EQUATION PARAMETERS

COMPARTMENT	COEFFICIENT	HALFLIFE(DAYS)
1	5.360E-01	2.500E-01
2	2.400E-01	6.000E+00
3	2.000E-01	2.000E+01
4	1.040E-03	1.500E+03
5	2.300E-02	5.000E+03

FRACTION EXCRETED IN URINE(FU)= 1.000E+00 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 1.650E+12 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS

DAYS POST INTAKE	NASAL BURDEN mg	LYMPH BURDEN mg	LUNG BURDEN mg	GI BURDEN mg	SYSTEMIC BURDEN mg	TOTAL BURDEN mg	ACCUMULATED FECES mg	ACCUMULATED URINE mg	INCREMENTAL URINE mg	INSTANTANEOUS URINE mg /L
1.00	4.773E-02	1.709E-04	2.115E-01	2.472E-01	4.120E-02	4.999E-01	3.974E-02	4.265E-02	4.265E-02	1.141E-02
2.00	8.437E-03	3.371E-04	1.779E-01	1.887E-01	3.730E-02	4.039E-01	1.658E-01	5.190E-02	9.255E-03	3.933E-03
3.00	1.492E-03	4.987E-04	1.604E-01	1.052E-01	3.504E-02	3.006E-01	2.718E-01	5.615E-02	4.250E-03	2.466E-03
4.00	2.637E-04	6.558E-04	1.508E-01	5.326E-02	3.307E-02	2.371E-01	3.334E-01	5.924E-02	3.083E-03	2.005E-03
5.00	4.661E-05	8.084E-04	1.450E-01	2.661E-02	3.125E-02	2.029E-01	3.652E-01	6.186E-02	2.629E-03	1.769E-03
6.00	8.240E-06	9.567E-04	1.413E-01	1.376E-02	2.957E-02	1.846E-01	3.811E-01	6.422E-02	2.358E-03	1.607E-03
7.00	1.457E-06	1.101E-03	1.386E-01	7.668E-03	2.802E-02	1.743E-01	3.894E-01	6.638E-02	2.158E-03	1.480E-03
8.00	2.575E-07	1.241E-03	1.363E-01	4.767E-03	2.660E-02	1.677E-01	3.939E-01	6.838E-02	1.995E-03	1.373E-03
9.00	4.552E-08	1.377E-03	1.344E-01	3.369E-03	2.530E-02	1.630E-01	3.967E-01	7.023E-02	1.856E-03	1.280E-03
10.00	8.047E-09	1.509E-03	1.326E-01	2.681E-03	2.411E-02	1.594E-01	3.987E-01	7.197E-02	1.734E-03	1.198E-03
11.00	1.422E-09	1.637E-03	1.308E-01	2.333E-03	2.302E-02	1.562E-01	4.002E-01	7.359E-02	1.626E-03	1.125E-03
12.00	2.515E-10	1.761E-03	1.291E-01	2.148E-03	2.202E-02	1.533E-01	4.016E-01	7.512E-02	1.529E-03	1.060E-03
13.00	4.445E-11	1.881E-03	1.275E-01	2.044E-03	2.110E-02	1.506E-01	4.028E-01	7.656E-02	1.442E-03	1.001E-03
14.00	7.858E-12	1.998E-03	1.259E-01	1.979E-03	2.025E-02	1.481E-01	4.040E-01	7.792E-02	1.363E-03	9.470E-04
15.00	1.389E-12	2.111E-03	1.243E-01	1.933E-03	1.947E-02	1.457E-01	4.051E-01	7.922E-02	1.291E-03	8.984E-04
16.00	2.456E-13	2.221E-03	1.227E-01	1.898E-03	1.875E-02	1.434E-01	4.062E-01	8.044E-02	1.226E-03	8.542E-04
17.00	4.341E-14	2.327E-03	1.212E-01	1.867E-03	1.808E-02	1.411E-01	4.073E-01	8.161E-02	1.167E-03	8.139E-04
18.00	7.674E-15	2.430E-03	1.196E-01	1.839E-03	1.747E-02	1.389E-01	4.084E-01	8.272E-02	1.113E-03	7.772E-04
19.00	1.357E-15	2.530E-03	1.181E-01	1.813E-03	1.689E-02	1.368E-01	4.094E-01	8.379E-02	1.064E-03	7.436E-04
20.00	2.398E-16	2.627E-03	1.166E-01	1.787E-03	1.636E-02	1.348E-01	4.104E-01	8.481E-02	1.019E-03	7.128E-04
21.00	4.239E-17	2.720E-03	1.151E-01	1.762E-03	1.586E-02	1.328E-01	4.115E-01	8.578E-02	9.779E-04	6.846E-04
22.00	7.494E-18	2.810E-03	1.137E-01	1.738E-03	1.540E-02	1.308E-01	4.125E-01	8.672E-02	9.400E-04	6.586E-04
23.00	1.325E-18	2.897E-03	1.122E-01	1.714E-03	1.496E-02	1.289E-01	4.135E-01	8.763E-02	9.051E-04	6.347E-04
24.00	2.342E-19	2.982E-03	1.108E-01	1.690E-03	1.456E-02	1.271E-01	4.144E-01	8.850E-02	8.730E-04	6.127E-04
25.00	4.140E-20	3.063E-03	1.094E-01	1.667E-03	1.418E-02	1.253E-01	4.154E-01	8.934E-02	8.433E-04	5.923E-04
26.00	7.318E-21	3.142E-03	1.080E-01	1.644E-03	1.382E-02	1.235E-01	4.163E-01	9.016E-02	8.158E-04	5.734E-04
27.00	1.294E-21	3.218E-03	1.067E-01	1.621E-03	1.348E-02	1.218E-01	4.173E-01	9.095E-02	7.903E-04	5.558E-04
28.00	2.287E-22	3.291E-03	1.053E-01	1.599E-03	1.316E-02	1.201E-01	4.182E-01	9.172E-02	7.666E-04	5.395E-04
29.00	4.043E-23	3.362E-03	1.040E-01	1.577E-03	1.286E-02	1.184E-01	4.191E-01	9.246E-02	7.445E-04	5.242E-04
30.00	7.147E-24	3.430E-03	1.027E-01	1.555E-03	1.258E-02	1.168E-01	4.200E-01	9.319E-02	7.239E-04	5.100E-04

URANIUM 238
ACUTE INHALATION INTAKE 1.000E+00 mg
100.0% CLASS D 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 5.000E-02

SYSTEMIC RETENTION EQUATION PARAMETERS

COMPARTMENT	COEFFICIENT	HALFLIFE(DAYS)
1	5.360E-01	2.500E-01
2	2.400E-01	6.000E+00
3	2.000E-01	2.000E+01
4	1.040E-03	1.500E+03
5	2.300E-02	5.000E+03

FRACTION EXCRETED IN URINE(FU)= 1.000E+00 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 1.650E+12 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS

DAYS POST INTAKE	NASAL BURDEN mg	LYMPH BURDEN mg	LUNG BURDEN mg	GI BURDEN mg	SYSTEMIC BURDEN mg	TOTAL BURDEN mg	ACCUMULATED FECES mg	ACCUMULATED URINE mg	INCREMENTAL URINE mg	INSTANTANEOUS URINE mg /L
1.00	2.367E-31	1.733E-02	7.995E-02	1.051E-01	2.093E-01	3.944E-01	4.106E-02	1.946E-01	1.946E-01	7.415E-02
2.00	0.000E+00	8.664E-03	2.429E-02	4.792E-02	1.988E-01	2.710E-01	9.838E-02	2.607E-01	6.609E-02	2.924E-02
3.00	0.000E+00	3.249E-03	7.155E-03	1.909E-02	1.866E-01	2.128E-01	1.272E-01	2.900E-01	2.929E-02	1.513E-02
4.00	0.000E+00	1.083E-03	2.060E-03	7.254E-03	1.745E-01	1.838E-01	1.390E-01	3.071E-01	1.719E-02	1.023E-02
5.00	0.000E+00	3.384E-04	5.826E-04	2.705E-03	1.632E-01	1.665E-01	1.436E-01	3.199E-01	1.275E-02	8.237E-03
6.00	0.000E+00	1.015E-04	1.626E-04	1.001E-03	1.529E-01	1.541E-01	1.453E-01	3.306E-01	1.074E-02	7.190E-03
7.00	0.000E+00	2.961E-05	4.487E-05	3.691E-04	1.435E-01	1.439E-01	1.459E-01	3.402E-01	9.538E-03	6.467E-03
8.00	0.000E+00	8.461E-06	1.228E-05	1.359E-04	1.349E-01	1.350E-01	1.462E-01	3.488E-01	8.632E-03	5.881E-03
9.00	0.000E+00	2.380E-06	3.333E-06	5.003E-05	1.270E-01	1.271E-01	1.462E-01	3.567E-01	7.869E-03	5.371E-03
10.00	0.000E+00	6.610E-07	8.995E-07	1.841E-05	1.198E-01	1.199E-01	1.463E-01	3.639E-01	7.195E-03	4.917E-03
11.00	0.000E+00	1.818E-07	2.414E-07	6.773E-06	1.132E-01	1.133E-01	1.463E-01	3.705E-01	6.593E-03	4.507E-03
12.00	0.000E+00	4.958E-08	6.448E-08	2.492E-06	1.072E-01	1.072E-01	1.463E-01	3.765E-01	6.051E-03	4.142E-03
13.00	0.000E+00	1.343E-08	1.715E-08	9.167E-07	1.016E-01	1.016E-01	1.463E-01	3.821E-01	5.563E-03	3.811E-03
14.00	0.000E+00	3.615E-09	4.546E-09	3.372E-07	9.651E-02	9.651E-02	1.463E-01	3.872E-01	5.122E-03	3.511E-03
15.00	0.000E+00	9.683E-10	1.201E-09	1.241E-07	9.178E-02	9.178E-02	1.463E-01	3.919E-01	4.723E-03	3.241E-03
16.00	0.000E+00	2.582E-10	3.164E-10	4.564E-08	8.742E-02	8.742E-02	1.463E-01	3.963E-01	4.363E-03	2.996E-03
17.00	0.000E+00	6.859E-11	8.314E-11	1.679E-08	8.338E-02	8.338E-02	1.463E-01	4.003E-01	4.037E-03	2.774E-03
18.00	0.000E+00	1.816E-11	2.179E-11	6.176E-09	7.964E-02	7.964E-02	1.463E-01	4.041E-01	3.741E-03	2.573E-03
19.00	0.000E+00	4.791E-12	5.701E-12	2.272E-09	7.617E-02	7.617E-02	1.463E-01	4.075E-01	3.472E-03	2.390E-03
20.00	0.000E+00	1.261E-12	1.488E-12	8.359E-10	7.294E-02	7.294E-02	1.463E-01	4.108E-01	3.228E-03	2.224E-03
21.00	0.000E+00	3.310E-13	3.878E-13	3.075E-10	6.994E-02	6.994E-02	1.463E-01	4.138E-01	3.006E-03	2.073E-03
22.00	0.000E+00	8.668E-14	1.009E-13	1.131E-10	6.713E-02	6.713E-02	1.463E-01	4.166E-01	2.804E-03	1.935E-03
23.00	0.000E+00	2.266E-14	2.621E-14	4.162E-11	6.451E-02	6.451E-02	1.463E-01	4.192E-01	2.620E-03	1.809E-03
24.00	0.000E+00	5.910E-15	6.798E-15	1.531E-11	6.206E-02	6.206E-02	1.463E-01	4.216E-01	2.451E-03	1.694E-03
25.00	0.000E+00	1.539E-15	1.761E-15	5.632E-12	5.976E-02	5.976E-02	1.463E-01	4.239E-01	2.297E-03	1.589E-03
26.00	0.000E+00	4.002E-16	4.557E-16	2.072E-12	5.761E-02	5.761E-02	1.463E-01	4.261E-01	2.156E-03	1.493E-03
27.00	0.000E+00	1.039E-16	1.178E-16	7.622E-13	5.558E-02	5.558E-02	1.463E-01	4.281E-01	2.027E-03	1.404E-03
28.00	0.000E+00	2.693E-17	3.040E-17	2.804E-13	5.367E-02	5.367E-02	1.463E-01	4.300E-01	1.908E-03	1.323E-03
29.00	0.000E+00	6.974E-18	7.841E-18	1.032E-13	5.187E-02	5.187E-02	1.463E-01	4.318E-01	1.799E-03	1.248E-03
30.00	0.000E+00	1.804E-18	2.020E-18	3.795E-14	5.018E-02	5.018E-02	1.463E-01	4.335E-01	1.698E-03	1.179E-03

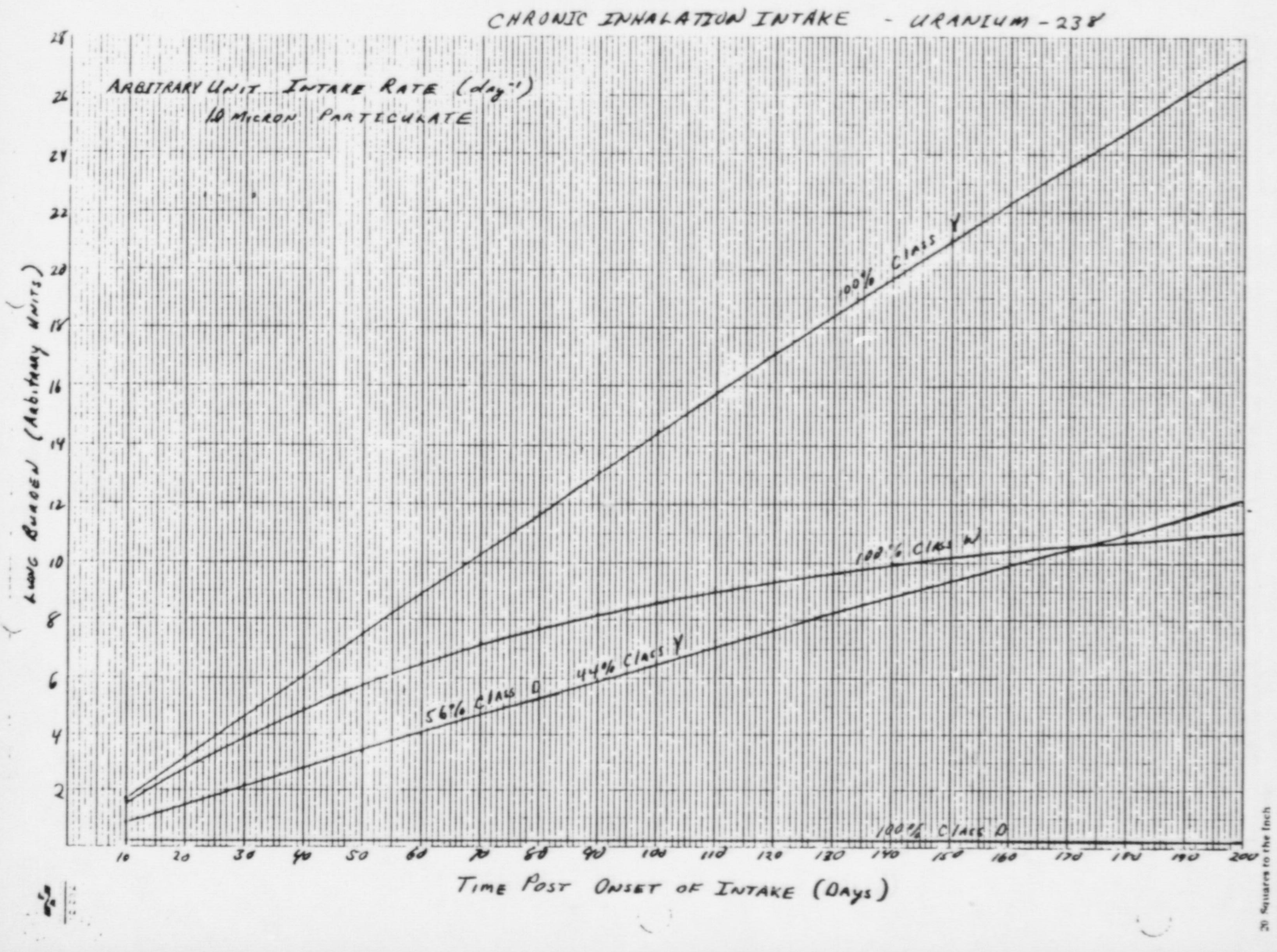
URANIUM 238
ACUTE INHALATION INTAKE 1.000E+00 mg
56.0% CLASS D 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 5.000E-02
44.0% CLASS Y 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 2.000E-03

SYSTEMIC RETENTION EQUATION PARAMETERS

COMPARTMENT	COEFFICIENT	HALFLIFE(DAYS)
1	5.360E-01	2.500E-01
2	2.400E-01	6.000E+00
3	2.000E-01	2.000E+01
4	1.040E-03	1.500E+03
5	2.300E-02	5.000E+03

FRACTION EXCRETED IN URINE(FU)= 1.000E+00 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 1.650E+12 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS

DAYS POST INTAKE	NASAL BURDEN mg	LYMPH BURDEN mg	LUNG BURDEN mg	GI BURDEN mg	SYSTEMIC BURDEN mg	TOTAL BURDEN mg	ACCUMULATED FECES mg	ACCUMULATED URINE mg	INCREMENTAL URINE mg	INSTANTANEOUS URINE mg /L
1.00	2.310E-02	9.727E-03	1.390E-01	1.944E-01	1.181E-01	4.516E-01	4.539E-02	1.100E-01	1.100E-01	4.178E-02
2.00	4.084E-03	4.898E-03	9.326E-02	1.268E-01	1.122E-01	3.322E-01	1.466E-01	1.472E-01	3.721E-02	1.646E-02
3.00	7.219E-04	1.888E-03	7.669E-02	6.460E-02	1.053E-01	2.466E-01	2.190E-01	1.637E-01	1.649E-02	8.528E-03
4.00	1.276E-04	6.976E-04	7.033E-02	3.032E-02	9.847E-02	1.991E-01	2.574E-01	1.734E-01	9.693E-03	5.769E-03
5.00	2.256E-05	3.033E-04	6.772E-02	1.391E-02	9.212E-02	1.737E-01	2.757E-01	1.806E-01	7.193E-03	4.651E-03
6.00	3.988E-06	1.933E-04	6.656E-02	6.410E-03	8.630E-02	1.593E-01	2.041E-01	1.866E-01	6.065E-03	4.061E-03
7.00	7.050E-07	1.756E-04	6.599E-02	3.015E-03	8.098E-02	1.500E-01	2.880E-01	1.920E-01	5.387E-03	3.653E-03
8.00	1.246E-07	1.863E-04	6.569E-02	1.466E-03	7.613E-02	1.433E-01	2.898E-01	1.969E-01	4.876E-03	3.322E-03
9.00	2.203E-08	2.053E-04	6.551E-02	7.502E-04	7.170E-02	1.380E-01	2.907E-01	2.013E-01	4.446E-03	3.035E-03
10.00	3.895E-09	2.268E-04	6.539E-02	4.145E-04	6.765E-02	1.334E-01	2.912E-01	2.054E-01	4.066E-03	2.778E-03
11.00	6.885E-10	2.489E-04	6.529E-02	2.548E-04	6.393E-02	1.295E-01	2.914E-01	2.091E-01	3.726E-03	2.548E-03
12.00	1.217E-10	2.712E-04	6.521E-02	1.780E-04	6.052E-02	1.259E-01	2.916E-01	2.125E-01	3.420E-03	2.341E-03
13.00	2.151E-11	2.935E-04	6.514E-02	1.407E-04	5.738E-02	1.227E-01	2.917E-01	2.157E-01	3.145E-03	2.154E-03
14.00	3.803E-12	3.158E-04	6.507E-02	1.224E-04	5.449E-02	1.197E-01	2.917E-01	2.186E-01	2.896E-03	1.986E-03
15.00	6.723E-13	3.380E-04	6.500E-02	1.133E-04	5.183E-02	1.169E-01	2.918E-01	2.213E-01	2.671E-03	1.833E-03
16.00	1.189E-13	3.601E-04	6.493E-02	1.088E-04	4.937E-02	1.144E-01	2.919E-01	2.237E-01	2.468E-03	1.695E-03
17.00	2.101E-14	3.823E-04	6.486E-02	1.064E-04	4.709E-02	1.121E-01	2.919E-01	2.260E-01	2.284E-03	1.570E-03
18.00	3.714E-15	4.044E-04	6.480E-02	1.052E-04	4.498E-02	1.099E-01	2.920E-01	2.281E-01	2.117E-03	1.456E-03
19.00	6.566E-16	4.264E-04	6.473E-02	1.045E-04	4.302E-02	1.079E-01	2.921E-01	2.301E-01	1.966E-03	1.353E-03
20.00	1.161E-16	4.484E-04	6.466E-02	1.041E-04	4.120E-02	1.060E-01	2.921E-01	2.319E-01	1.828E-03	1.260E-03
21.00	2.052E-17	4.703E-04	6.459E-02	1.038E-04	3.951E-02	1.042E-01	2.922E-01	2.336E-01	1.703E-03	1.174E-03
22.00	3.627E-18	4.922E-04	6.453E-02	1.036E-04	3.793E-02	1.026E-01	2.922E-01	2.352E-01	1.589E-03	1.097E-03
23.00	6.412E-19	5.141E-04	6.446E-02	1.034E-04	3.645E-02	1.010E-01	2.923E-01	2.367E-01	1.485E-03	1.026E-03
24.00	1.133E-19	5.359E-04	6.439E-02	1.033E-04	3.507E-02	9.956E-02	2.924E-01	2.381E-01	1.390E-03	9.609E-04
25.00	2.004E-20	5.577E-04	6.433E-02	1.031E-04	3.377E-02	9.820E-02	2.924E-01	2.394E-01	1.303E-03	9.016E-04
26.00	3.542E-21	5.794E-04	6.426E-02	1.030E-04	3.256E-02	9.692E-02	2.925E-01	2.406E-01	1.224E-03	8.472E-04
27.00	6.262E-22	6.011E-04	6.419E-02	1.028E-04	3.141E-02	9.571E-02	2.925E-01	2.418E-01	1.151E-03	7.973E-04
28.00	1.107E-22	6.227E-04	6.413E-02	1.027E-04	3.034E-02	9.457E-02	2.926E-01	2.428E-01	1.084E-03	7.514E-04
29.00	1.957E-23	6.443E-04	6.406E-02	1.026E-04	2.932E-02	9.349E-02	2.926E-01	2.439E-01	1.022E-03	7.091E-04
30.00	3.459E-24	6.659E-04	6.399E-02	1.024E-04	2.837E-02	9.246E-02	2.927E-01	2.440E-01	9.650E-04	6.701E-04



CHRONIC INHALATION INTAKE - URANIUM-238
ARBITRARY UNIT INTAKE RATE (day⁻¹)
1.0 MICRON PARTICULATE
100% CLASS Y
100% CLASS W
56% CLASS D 44% CLASS Y
100% CLASS D
LUNG BURDEN (ARBITRARY UNITS)
2
4
6
8
10
12
14
16
18
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22
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28
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60
70
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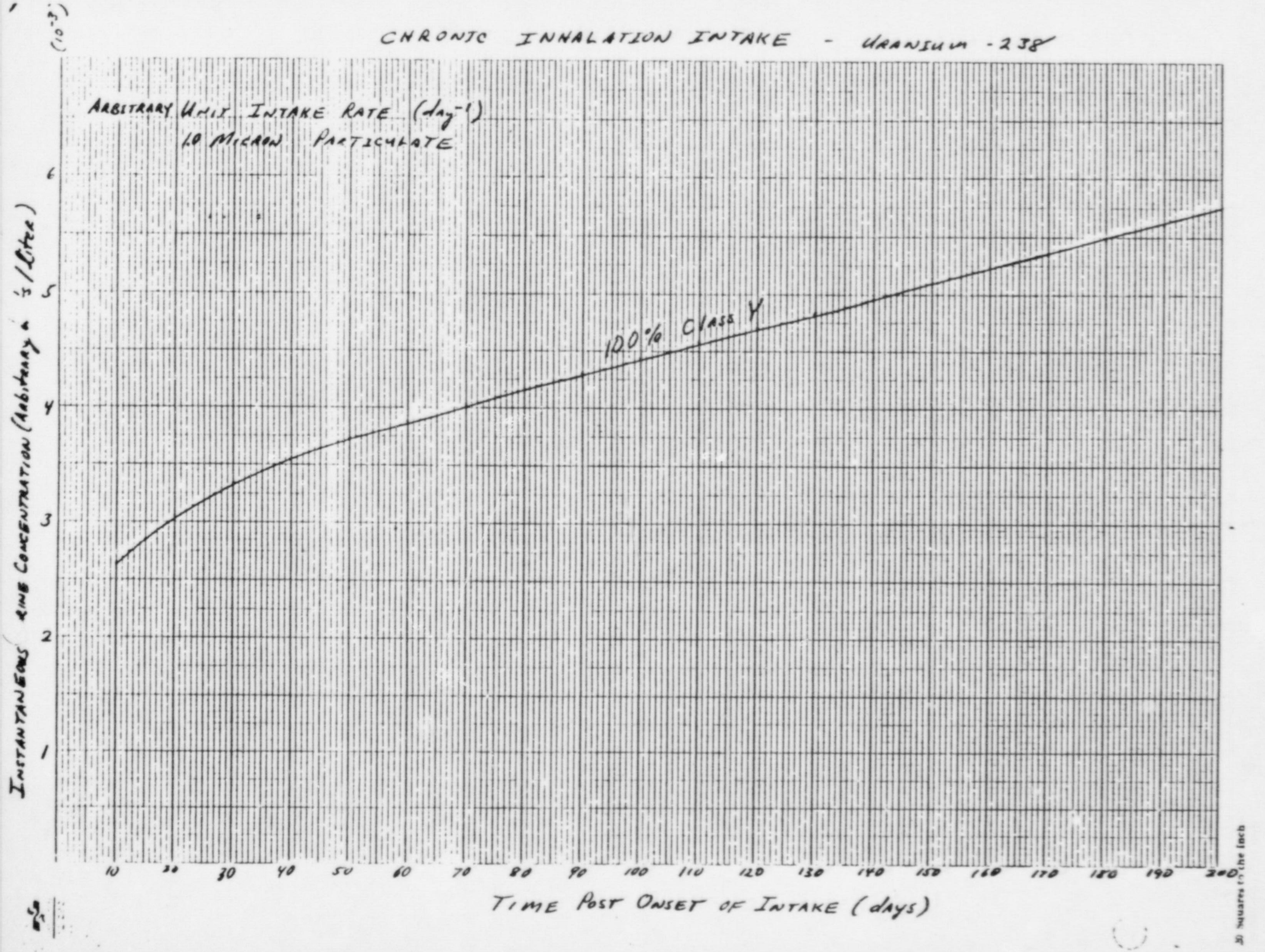
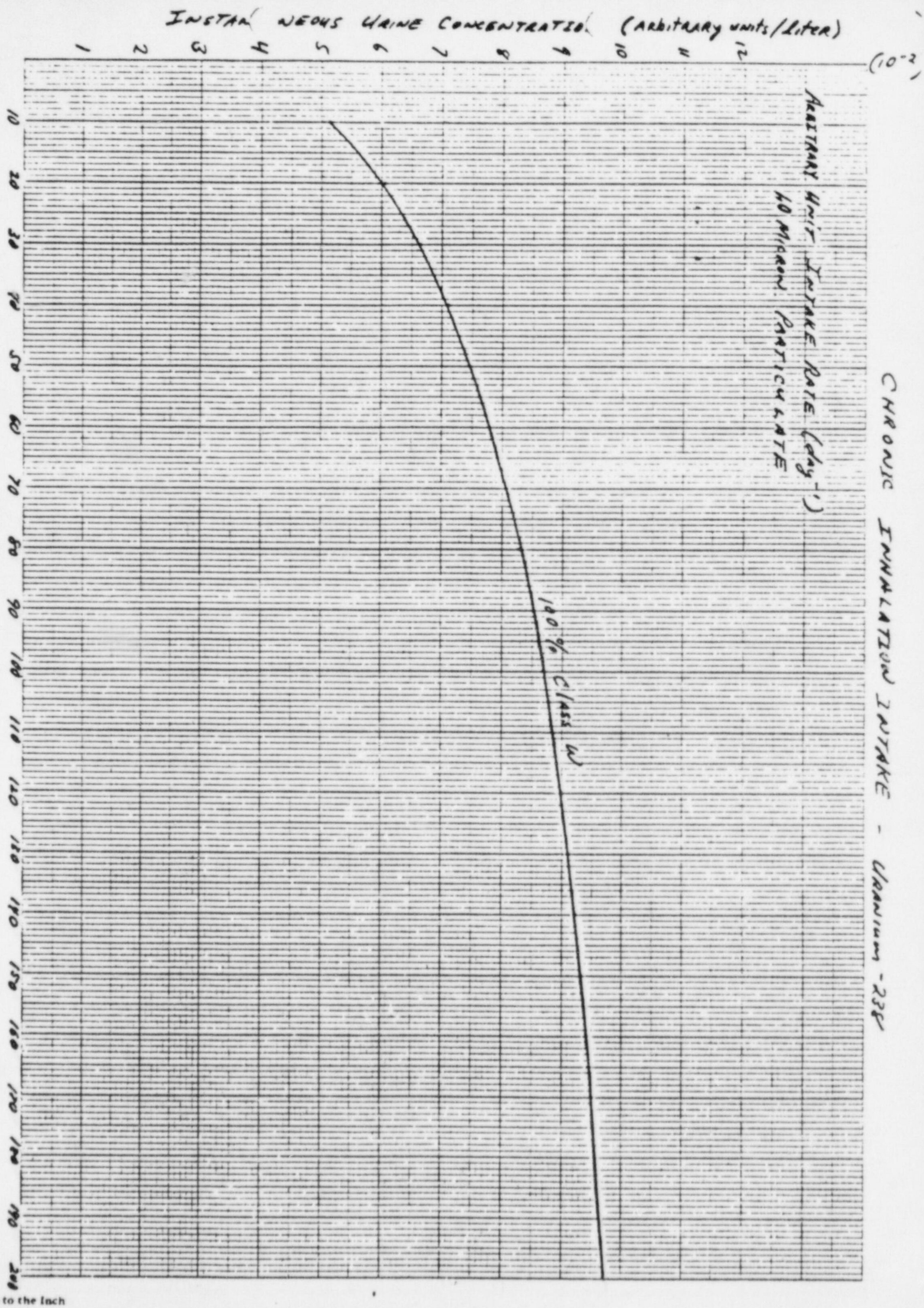
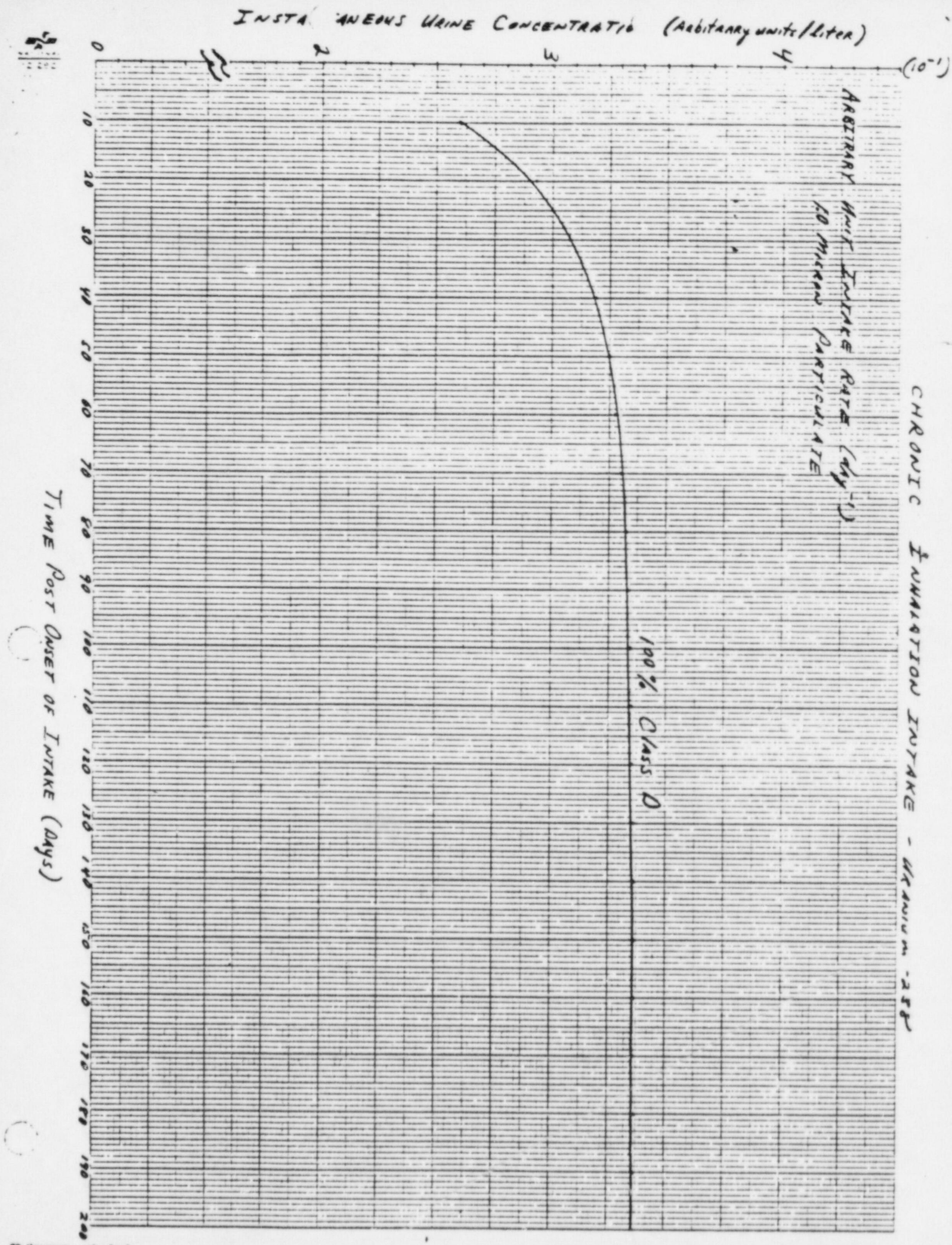
160
170
180
190
200
TIME POST ONSET OF INTAKE (DAYS)
20 Squares to the Inch

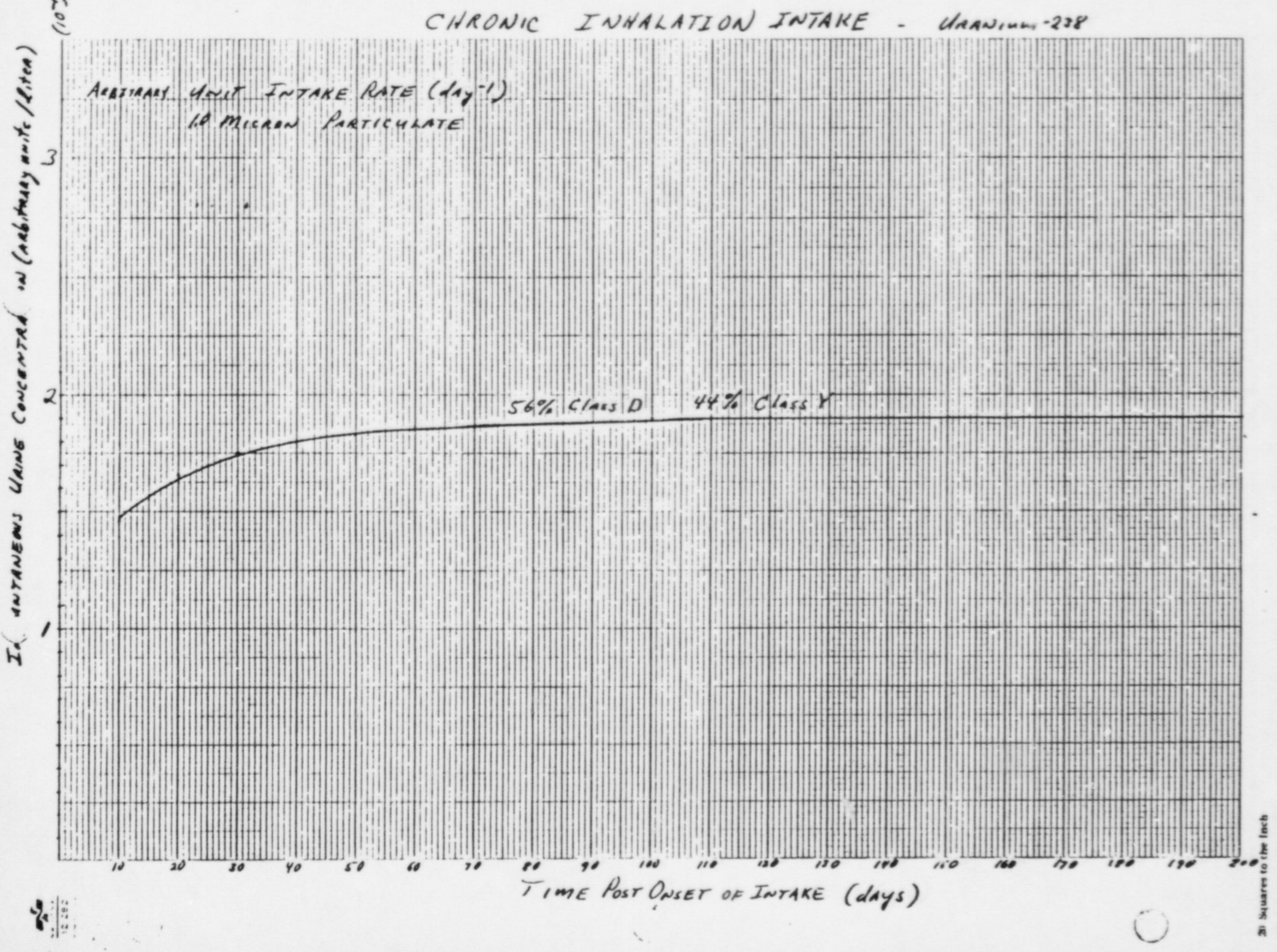

CHRONIC INHALATION INTAKE - URANIUM-238
ARBITRARY UNIT INTAKE RATE (day⁻¹)
1.0 MICRON PARTICULATE
100% CLASS Y
INSTANTANEOUS URINE CONCENTRATION (Arbitrary u's/Liter)
(10⁻³)
1
2
3
4
5
6
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
TIME POST ONSET OF INTAKE (days)
20 Squares to the Inch



20 Squares to the Inch



20 Squares to the Inch



CHRONIC INHALATION INTAKE - URANIUM-238
ARBITRARY UNIT INTAKE RATE (day-1)
1.0 MICRON PARTICULATE
56% Class D 44% Class Y
(10-7)
3
2
1
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
TIME POST ONSET OF INTAKE (days)
20 Squares to the Inch

THORIUM 234
CHRONIC INHALATION INTAKE 3.000E-01 µCi/DAY
100.0% CLASS Y 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 2.000E-04

SYSTEMIC RETENTION EQUATION PARAMETERS

COMPARTMENT	COEFFICIENT	HALFLIFE(DAYS)
1	1.000E-01	5.000E-01
2	2.000E-01	7.000E+02
3	7.000E-01	8.000E+03

FRACTION EXCRETED IN URINE(FU)= 9.000E-01 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 2.410E+01 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS
CHRONIC INTAKE PERIOD= 2.000E+02 DAYS

DAYS POST INTAKE	NASAL BURDEN µCi	LYMPH BURDEN µCi	LUNG BURDEN µCi	GI BURDEN µCi	SYSTEMIC BURDEN µCi	TOTAL BURDEN µCi	ACCUMULATED FECES µCi	ACCUMULATED URINE µCi	INCREMENTAL URINE µCi	INSTANTANEOUS URINE µCi/L
10.00	5.059E-02	6.410E-04	4.458E-01	2.363E-01	9.368E-03	6.915E-01	8.994E-01	8.638E-04	1.072E-04	7.790E-05
20.00	5.059E-02	2.119E-03	7.348E-01	2.370E-01	1.665E-02	9.004E-01	1.834E+00	1.619E-03	1.122E-04	8.144E-05
30.00	5.059E-02	3.960E-03	9.493E-01	2.374E-01	2.232E-02	1.209E+00	2.536E+00	2.223E-03	1.159E-04	8.413E-05
40.00	5.059E-02	5.879E-03	1.108E+00	2.376E-01	2.674E-02	1.373E+00	3.065E+00	2.705E-03	1.188E-04	8.618E-05
50.00	5.059E-02	7.714E-03	1.227E+00	2.378E-01	3.018E-02	1.495E+00	3.463E+00	3.088E-03	1.210E-04	8.774E-05
60.00	5.059E-02	9.382E-03	1.314E+00	2.379E-01	3.285E-02	1.585E+00	3.762E+00	3.391E-03	1.227E-04	8.893E-05
70.00	5.059E-02	1.085E-02	1.380E+00	2.380E-01	3.492E-02	1.653E+00	3.987E+00	3.632E-03	1.239E-04	8.983E-05
80.00	5.059E-02	1.210E-02	1.428E+00	2.381E-01	3.652E-02	1.703E+00	4.156E+00	3.821E-03	1.249E-04	9.052E-05
90.00	5.059E-02	1.316E-02	1.464E+00	2.382E-01	3.777E-02	1.740E+00	4.283E+00	3.971E-03	1.256E-04	9.104E-05
100.00	5.059E-02	1.404E-02	1.490E+00	2.382E-01	3.873E-02	1.767E+00	4.379E+00	4.089E-03	1.262E-04	9.144E-05
110.00	5.059E-02	1.476E-02	1.510E+00	2.382E-01	3.947E-02	1.788E+00	4.450E+00	4.181E-03	1.266E-04	9.174E-05
120.00	5.059E-02	1.534E-02	1.525E+00	2.383E-01	4.004E-02	1.803E+00	4.504E+00	4.254E-03	1.269E-04	9.197E-05
130.00	5.059E-02	1.582E-02	1.536E+00	2.383E-01	4.048E-02	1.815E+00	4.545E+00	4.311E-03	1.272E-04	9.214E-05
140.00	5.059E-02	1.619E-02	1.544E+00	2.383E-01	4.083E-02	1.823E+00	4.576E+00	4.355E-03	1.273E-04	9.228E-05
150.00	5.059E-02	1.650E-02	1.550E+00	2.383E-01	4.109E-02	1.829E+00	4.599E+00	4.390E-03	1.275E-04	9.238E-05
160.00	5.059E-02	1.674E-02	1.554E+00	2.383E-01	4.129E-02	1.834E+00	4.616E+00	4.417E-03	1.276E-04	9.245E-05
170.00	5.059E-02	1.693E-02	1.558E+00	2.383E-01	4.145E-02	1.837E+00	4.629E+00	4.438E-03	1.277E-04	9.251E-05
180.00	5.059E-02	1.708E-02	1.560E+00	2.383E-01	4.157E-02	1.840E+00	4.639E+00	4.455E-03	1.277E-04	9.255E-05
190.00	5.059E-02	1.720E-02	1.562E+00	2.383E-01	4.166E-02	1.842E+00	4.646E+00	4.468E-03	1.278E-04	9.259E-05
200.00	5.059E-02	1.729E-02	1.563E+00	2.383E-01	4.173E-02	1.843E+00	4.651E+00	4.478E-03	1.278E-04	9.261E-05
210.00	1.131E-09	1.672E-02	1.119E+00	1.991E-03	3.241E-02	1.153E+00	3.756E+00	3.621E-03	2.060E-05	1.473E-05
220.00	2.527E-17	1.530E-02	8.303E-01	1.321E-03	2.310E-02	8.568E-01	2.825E+00	2.872E-03	1.568E-05	1.121E-05
230.00	5.649E-25	1.350E-02	6.164E-01	9.767E-04	1.953E-02	6.369E-01	2.125E+00	2.273E-03	1.193E-05	8.528E-06
240.00	1.263E-32	1.161E-02	4.576E-01	7.225E-04	1.514E-02	4.734E-01	1.598E+00	1.795E-03	9.075E-06	6.487E-06
250.00	0.000E+00	9.804E-03	3.397E-01	5.345E-04	1.172E-02	3.520E-01	1.201E+00	1.415E-03	6.901E-06	4.933E-06
260.00	0.000E+00	8.157E-03	2.522E-01	3.954E-04	9.064E-03	2.617E-01	9.034E-01	1.113E-03	5.246E-06	3.750E-06
270.00	0.000E+00	6.708E-03	1.872E-01	2.925E-04	7.005E-03	1.945E-01	6.793E-01	8.747E-04	3.986E-06	2.849E-06
280.00	0.000E+00	5.465E-03	1.390E-01	2.163E-04	5.409E-03	1.446E-01	5.108E-01	6.862E-04	3.029E-06	2.165E-06
290.00	0.000E+00	4.417E-03	1.032E-01	1.600E-04	4.173E-03	1.075E-01	3.840E-01	5.375E-04	2.300E-06	1.644E-06
300.00	0.000E+00	3.547E-03	7.662E-02	1.104E-04	3.217E-03	7.995E-02	2.887E-01	4.206E-04	1.746E-06	1.248E-06

THORIUM 234
CHRONIC INHALATION INTAKE 3.000E-01 µCi/DAY
100.0% CLASS W 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 1.000E-04

SYSTEMIC RETENTION EQUATION PARAMETERS

COMPARTMENT	COEFFICIENT	HALFLIFE(DAYS)
1	1.000E-01	5.000E-01
2	2.000E-01	7.000E+02
3	7.000E-01	8.000E+03

FRACTION EXCRETED IN URINE(FU)= 9.000E-01 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 2.410E+01 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS
CHRONIC INTAKE PERIOD= 2.000E+02 DAYS

DAYS POST INTAKE	NASAL BURDEN µCi	LYMPH BURDEN µCi	LUNG BURDEN µCi	GI BURDEN µCi	SYSTEMIC BURDEN µCi	TOTAL BURDEN µCi	ACCUMULATED FECES µCi	ACCUMULATED URINE µCi	INCREMENTAL URINE µCi	INSTANTANEOUS URINE µCi/L
10.00	4.611E-02	1.966E-03	4.227E-01	2.076E-01	1.710E-01	8.013E-01	7.775E-01	1.576E-02	1.968E-03	1.431E-03
20.00	4.611E-02	6.014E-03	6.666E-01	2.118E-01	3.064E-01	1.185E+00	1.610E+00	2.978E-02	2.083E-03	1.513E-03
30.00	4.611E-02	1.046E-02	8.277E-01	2.144E-01	4.133E-01	1.455E+00	2.251E+00	4.114E-02	2.165E-03	1.572E-03
40.00	4.611E-02	1.454E-02	9.341E-01	2.161E-01	4.972E-01	1.647E+00	2.742E+00	5.026E-02	2.224E-03	1.613E-03
50.00	4.611E-02	1.798E-02	1.004E+00	2.172E-01	5.625E-01	1.784E+00	3.117E+00	5.753E-02	2.266E-03	1.643E-03
60.00	4.611E-02	2.072E-02	1.051E+00	2.179E-01	6.132E-01	1.882E+00	3.403E+00	6.328E-02	2.296E-03	1.665E-03
70.00	4.611E-02	2.285E-02	1.081E+00	2.184E-01	6.523E-01	1.952E+00	3.620E+00	6.782E-02	2.317E-03	1.680E-03
80.00	4.611E-02	2.444E-02	1.101E+00	2.187E-01	6.824E-01	2.002E+00	3.785E+00	7.138E-02	2.333E-03	1.691E-03
90.00	4.611E-02	2.563E-02	1.115E+00	2.189E-01	7.054E-01	2.039E+00	3.910E+00	7.417E-02	2.344E-03	1.699E-03
100.00	4.611E-02	2.649E-02	1.124E+00	2.190E-01	7.230E-01	2.066E+00	4.005E+00	7.633E-02	2.352E-03	1.704E-03
110.00	4.611E-02	2.712E-02	1.129E+00	2.191E-01	7.364E-01	2.085E+00	4.076E+00	7.802E-02	2.358E-03	1.709E-03
120.00	4.611E-02	2.756E-02	1.133E+00	2.191E-01	7.466E-01	2.099E+00	4.130E+00	7.933E-02	2.362E-03	1.711E-03
130.00	4.611E-02	2.788E-02	1.136E+00	2.192E-01	7.544E-01	2.109E+00	4.170E+00	8.034E-02	2.365E-03	1.714E-03
140.00	4.611E-02	2.810E-02	1.137E+00	2.192E-01	7.603E-01	2.117E+00	4.201E+00	8.112E-02	2.367E-03	1.715E-03
150.00	4.611E-02	2.826E-02	1.138E+00	2.192E-01	7.647E-01	2.122E+00	4.224E+00	8.172E-02	2.369E-03	1.716E-03
160.00	4.611E-02	2.837E-02	1.139E+00	2.192E-01	7.681E-01	2.126E+00	4.242E+00	8.218E-02	2.370E-03	1.717E-03
170.00	4.611E-02	2.845E-02	1.140E+00	2.192E-01	7.706E-01	2.129E+00	4.255E+00	8.253E-02	2.371E-03	1.718E-03
180.00	4.611E-02	2.850E-02	1.140E+00	2.192E-01	7.725E-01	2.132E+00	4.264E+00	8.281E-02	2.371E-03	1.718E-03
190.00	4.611E-02	2.853E-02	1.140E+00	2.192E-01	7.739E-01	2.133E+00	4.272E+00	8.302E-02	2.372E-03	1.718E-03
200.00	4.611E-02	2.056E-02	1.140E+00	2.192E-01	7.750E-01	2.135E+00	4.277E+00	8.318E-02	2.372E-03	1.719E-03
210.00	1.028E-09	2.661E-02	7.177E-01	1.159E-02	6.048E-01	1.334E+00	3.504E+00	6.754E-02	4.042E-04	2.880E-04
220.00	2.297E-17	2.257E-02	4.738E-01	7.436E-03	4.701E-01	9.513E-01	2.674E+00	5.361E-02	2.891E-04	2.060E-04
230.00	5.136E-25	1.813E-02	3.128E-01	4.855E-03	3.636E-01	6.812E-01	2.036E+00	4.232E-02	2.070E-04	1.475E-04
240.00	1.148E-32	1.406E-02	2.064E-01	3.170E-03	2.801E-01	4.897E-01	1.547E+00	3.326E-02	1.484E-04	1.058E-04
250.00	0.000E+00	1.063E-02	1.362E-01	2.070E-03	2.150E-01	3.533E-01	1.173E+00	2.603E-02	1.066E-04	7.597E-05
260.00	0.000E+00	7.884E-03	8.991E-02	1.352E-03	1.645E-01	2.558E-01	8.880E-01	2.031E-02	7.665E-05	5.464E-05
270.00	0.000E+00	5.765E-03	5.932E-02	8.826E-04	1.256E-01	1.858E-01	6.715E-01	1.579E-02	5.522E-05	3.936E-05
280.00	0.000E+00	4.167E-03	3.914E-02	5.763E-04	9.563E-02	1.353E-01	5.072E-01	1.225E-02	3.984E-05	2.841E-05
290.00	0.000E+00	2.984E-03	2.582E-02	3.763E-04	7.267E-02	9.886E-02	3.827E-01	9.482E-03	2.080E-05	2.053E-05
300.00	0.000E+00	2.120E-03	1.703E-02	2.457E-04	5.513E-02	7.240E-02	2.886E-01	7.324E-03	2.085E-05	1.487E-05

THORIUM 234
ACUTE INHALATION INTAKE 1.000E+00 uCi
100.0% CLASS Y 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 2.000E-04

SYSTEMIC RETENTION EQUATION PARAMETERS

COMPARTMENT	COEFFICIENT	HALFLIFE(DAYS)
1	1.000E-01	5.000E-01
2	2.000E-01	7.000E+02
3	7.000E-01	8.000E+03

FRACTION EXCRETED IN URINE(FU)= 9.000E-01 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 2.410E+01 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS

DAYS POST INTAKE	NASAL BURDEN uCi	LYMPH BURDEN uCi	LUNG BURDEN uCi	GI BURDEN uCi	SYSTEMIC BURDEN uCi	TOTAL BURDEN uCi	ACCUMULATED FECES uCi	ACCUMULATED URINE uCi	INCREMENTAL URINE uCi	INSTANTANEOUS URINE uCi/L
1.00	5.101E-02	5.046E-05	2.080E-01	2.998E-01	3.492E-03	5.113E-01	4.951E-02	2.517E-04	2.517E-04	8.830E-05
2.00	8.762E-03	9.796E-05	1.709E-01	2.148E-01	[illegible]	3.891E-01	1.966E-01	3.116E-04	6.702E-05	2.352E-05
3.00	1.505E-03	1.426E-04	1.515E-01	1.126E-01	3.260E-03	2.674E-01	3.086E-01	[illegible]	1.861E-05	7.167E-06
4.00	2.585E-04	1.846E-04	1.401E-01	5.330E-02	3.178E-03	1.966E-01	3.643E-01	3.187E-04	6.383E-06	3.015E-06
5.00	4.440E-05	2.240E-04	1.327E-01	2.444E-02	3.100E-03	1.602E-01	3.850E-01	3.129E-04	3.247E-06	1.925E-06
6.00	7.627E-06	2.609E-04	1.271E-01	1.121E-02	3.025E-03	1.414E-01	3.884E-01	3.064E-04	2.398E-06	1.610E-06
7.00	1.316E-06	2.955E-04	1.226E-01	5.229E-03	2.951E-03	1.308E-01	3.840E-01	2.998E-04	2.130E-06	1.494E-06
8.00	2.250E-07	3.278E-04	1.186E-01	2.515E-03	2.879E-03	1.240E-01	3.762E-01	2.934E-04	2.015E-06	1.432E-06
9.00	3.865E-08	3.579E-04	1.149E-01	1.270E-03	2.809E-03	1.190E-01	3.670E-01	2.870E-04	1.943E-06	1.386E-06
10.00	6.639E-09	3.860E-04	1.115E-01	6.903E-04	2.740E-03	1.149E-01	3.573E-01	2.807E-04	[illegible]	1.346E-06
11.00	1.140E-09	4.122E-04	1.081E-01	4.166E-04	2.673E-03	1.112E-01	3.476E-01	2.746E-04	1.832E-06	1.309E-06
12.00	1.959E-10	4.365E-04	1.050E-01	2.848E-04	2.608E-03	1.078E-01	3.380E-01	2.686E-04	1.782E-06	1.274E-06
13.00	3.364E-11	4.590E-04	1.019E-01	2.196E-04	2.544E-03	1.046E-01	3.286E-01	2.627E-04	1.734E-06	1.239E-06
14.00	5.779E-12	4.798E-04	9.886E-02	1.860E-04	2.482E-03	1.015E-01	3.194E-01	2.570E-04	1.687E-06	1.206E-06
15.00	9.926E-13	4.990E-04	9.596E-02	1.675E-04	2.421E-03	9.855E-02	3.104E-01	2.513E-04	1.642E-06	1.174E-06
16.00	1.705E-13	5.166E-04	9.314E-02	1.563E-04	2.361E-03	9.566E-02	3.017E-01	2.458E-04	1.598E-06	1.142E-06
17.00	2.928E-14	5.328E-04	9.041E-02	1.486E-04	2.303E-03	9.286E-02	2.932E-01	2.404E-04	1.555E-06	1.112E-06
18.00	5.030E-15	5.476E-04	8.775E-02	1.427E-04	2.247E-03	9.014E-02	2.850E-01	2.351E-04	1.513E-06	1.082E-06
19.00	8.640E-16	5.611E-04	8.518E-02	1.378E-04	2.192E-03	8.750E-02	2.770E-01	2.299E-04	1.473E-06	1.053E-06
20.00	1.484E-16	5.733E-04	8.267E-02	1.334E-04	2.138E-03	8.495E-02	2.692E-01	2.248E-04	1.433E-06	1.025E-06
21.00	2.549E-17	5.843E-04	8.025E-02	1.292E-04	2.085E-03	8.246E-02	2.617E-01	2.198E-04	1.395E-06	9.970E-07
22.00	4.378E-18	5.942E-04	7.789E-02	1.253E-04	2.034E-03	8.005E-02	2.543E-01	2.149E-04	1.357E-06	9.703E-07
23.00	7.520E-19	6.030E-04	7.560E-02	1.215E-04	1.984E-03	7.771E-02	2.472E-01	2.102E-04	1.321E-06	9.443E-07
24.00	1.292E-19	6.107E-04	7.338E-02	1.179E-04	1.935E-03	7.544E-02	[illegible]	2.055E-04	1.285E-06	9.189E-07
25.00	2.219E-20	6.175E-04	7.123E-02	1.144E-04	1.887E-03	7.323E-02	2.335E-01	2.009E-04	1.251E-06	8.943E-07
26.00	3.811E-21	6.234E-04	6.914E-02	1.110E-04	1.841E-03	7.109E-02	2.269E-01	1.964E-04	1.217E-06	8.703E-07
27.00	6.546E-22	6.284E-04	6.711E-02	1.077E-04	1.795E-03	6.901E-02	2.206E-01	1.921E-04	1.185E-06	8.469E-07
28.00	1.124E-22	6.325E-04	6.514E-02	1.045E-04	1.751E-03	6.699E-02	2.144E-01	1.878E-04	1.153E-06	8.242E-07
29.00	1.931E-23	6.359E-04	6.323E-02	1.014E-04	1.708E-03	6.504E-02	2.084E-01	1.836E-04	1.122E-06	8.020E-07
30.00	3.317E-24	6.386E-04	6.137E-02	9.839E-05	1.665E-03	6.313E-02	2.025E-01	1.795E-04	1.092E-06	7.805E-07

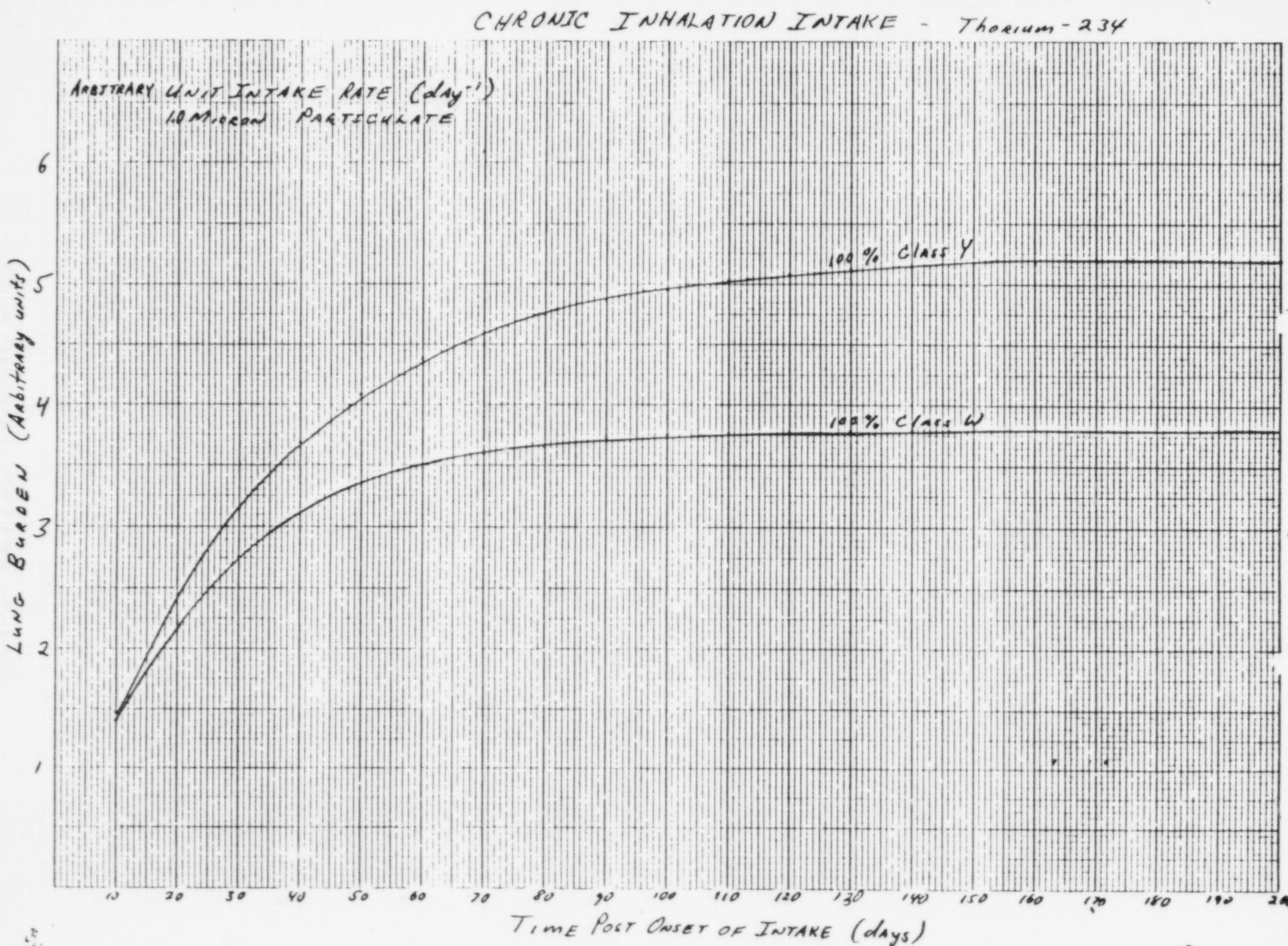
THORIUM 234
ACUTE INHALATION INTAKE 1.000E+00 uCi
100.0% CLASS W 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 2.000E-04

SYSTEMIC RETENTION EQUATION PARAMETERS

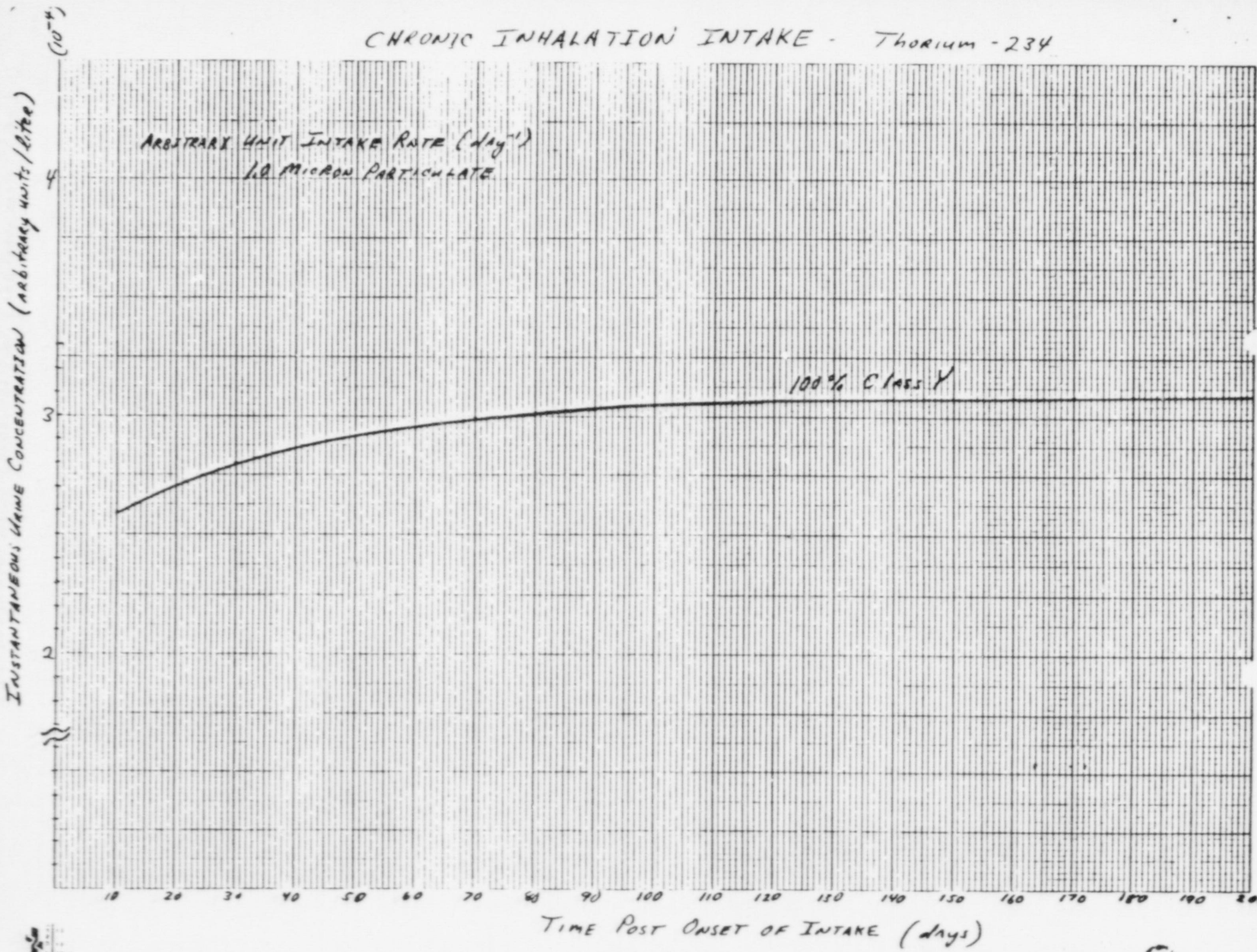
COMPARTMENT	COEFFICIENT	HALFLIFE(DAYS)
1	1.000E-01	5.000E-01
2	2.000E-01	7.000E+02
3	7.000E-01	8.000E+03

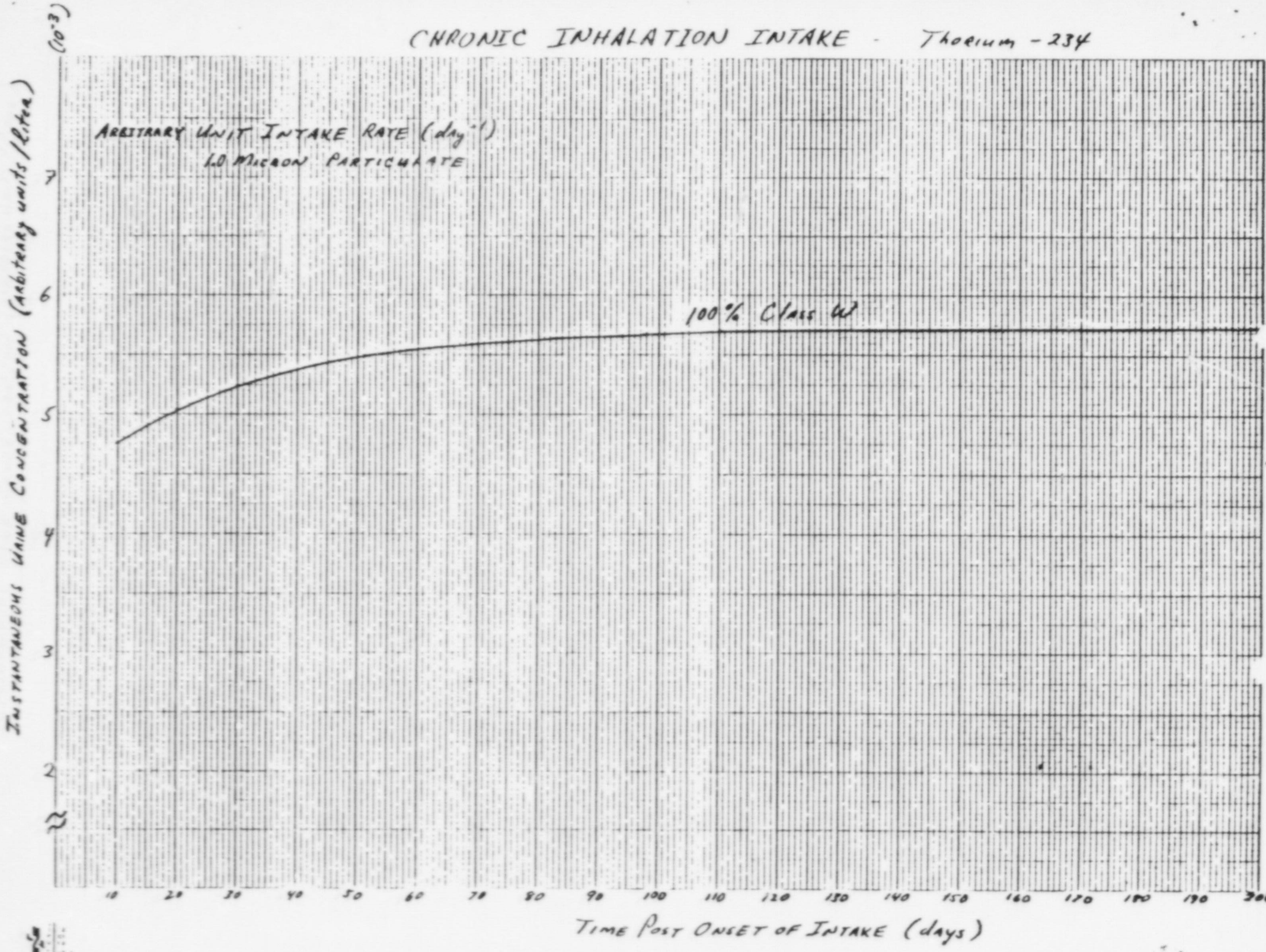
FRACTION EXCRETED IN URINE(FU)= 9.000E-01 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 2.410E+01 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS

DAYS POST INTAKE	NASAL BURDEN uCi	LYMPH BURDEN uCi	LUNG BURDEN uCi	GI BURDEN uCi	SYSTEMIC BURDEN uCi	TOTAL BURDEN uCi	ACCUMULATED FECES uCi	ACCUMULATED URINE uCi	INCREMENTAL URINE uCi	INSTANTANEOUS URINE uCi/L
1.00	4.638E-02	1.661E-04	2.055E-01	2.518E-01	6.346E-02	5.207E-01	3.996E-02	4.598E-03	4.598E-03	1.584E-03
2.00	7.966E-03	3.183E-04	1.679E-01	1.881E-01	6.084E-02	4.169E-01	1.636E-01	5.662E-03	1.194E-03	4.173E-04
3.00	1.368E-03	4.575E-04	1.471E-01	1.021E-01	5.921E-02	3.084E-01	2.616E-01	5.835E-03	3.337E-04	1.322E-04
4.00	2.350E-04	5.845E-04	1.344E-01	5.027E-02	5.785E-02	2.425E-01	3.124E-01	5.793E-03	1.228E-04	6.184E-05
5.00	4.037E-05	7.001E-04	1.256E-01	2.440E-02	5.656E-02	2.066E-01	3.327E-01	5.699E-03	7.011E-05	4.370E-05
6.00	6.934E-06	8.051E-04	1.189E-01	1.226E-02	5.531E-02	1.865E-01	3.374E-01	5.593E-03	5.593E-05	3.832E-05
7.00	1.191E-06	9.001E-04	1.133E-01	6.628E-03	5.409E-02	1.740E-01	3.350E-01	5.485E-03	5.116E-05	3.608E-05
8.00	2.046E-07	9.857E-04	1.083E-01	3.999E-03	5.289E-02	1.652E-01	3.293E-01	5.379E-03	4.875E-05	3.464E-05
9.00	3.514E-08	1.063E-03	1.037E-01	2.742E-03	5.171E-02	1.582E-01	3.223E-01	5.273E-03	4.695E-05	3.342E-05
10.00	6.035E-09	1.131E-03	9.943E-02	2.117E-03	5.055E-02	1.521E-01	3.147E-01	5.169E-03	4.534E-05	3.230E-05
11.00	1.037E-09	1.193E-03	9.535E-02	1.789E-03	4.941E-02	1.465E-01	3.070E-01	5.066E-03	4.382E-05	3.122E-05
12.00	1.781E-10	1.247E-03	9.145E-02	1.600E-03	4.829E-02	1.413E-01	2.993E-01	4.965E-03	4.235E-05	3.018E-05
13.00	3.058E-11	1.294E-03	8.772E-02	1.479E-03	4.720E-02	1.364E-01	2.917E-01	4.865E-03	4.094E-05	2.917E-05
14.00	5.253E-12	1.336E-03	8.415E-02	1.391E-03	4.612E-02	1.317E-01	2.842E-01	4.767E-03	3.958E-05	2.820E-05
15.00	9.024E-13	1.371E-03	8.073E-02	1.320E-03	4.506E-02	[illegible]	2.769E-01	4.670E-03	3.826E-05	2.726E-05
16.00	1.550E-13	1.402E-03	7.745E-02	1.259E-03	4.403E-02	1.227E-01	2.698E-01	4.575E-03	3.699E-05	2.635E-05
17.00	2.662E-14	1.427E-03	7.430E-02	1.204E-03	4.301E-02	1.185E-01	2.629E-01	4.481E-03	3.576E-05	2.548E-05
18.00	4.573E-15	1.448E-03	7.128E-02	1.152E-03	4.202E-02	1.145E-01	2.561E-01	4.388E-03	3.457E-05	2.463E-05
19.00	7.854E-16	1.465E-03	6.838E-02	1.103E-03	4.104E-02	1.105E-01	2.495E-01	4.297E-03	3.342E-05	2.381E-05
20.00	1.349E-16	1.478E-03	6.560E-02	1.057E-03	4.009E-02	1.067E-01	2.430E-01	4.208E-03	3.231E-05	2.302E-05
21.00	2.317E-17	1.487E-03	6.294E-02	1.013E-03	3.915E-02	1.031E-01	2.367E-01	4.120E-03	3.123E-05	2.225E-05
22.00	3.980E-18	1.493E-03	6.038E-02	9.703E-04	3.823E-02	9.958E-02	2.306E-01	4.033E-03	3.019E-05	2.151E-05
23.00	6.837E-19	1.495E-03	5.792E-02	9.298E-04	3.733E-02	9.619E-02	2.246E-01	3.948E-03	2.919E-05	2.080E-05
24.00	1.174E-19	1.495E-03	5.557E-02	8.910E-04	3.645E-02	9.291E-02	2.187E-01	3.864E-03	2.822E-05	2.011E-05
25.00	2.017E-20	1.493E-03	5.331E-02	8.538E-04	3.559E-02	8.975E-02	2.130E-01	3.782E-03	2.728E-05	1.944E-05
26.00	3.465E-21	1.487E-03	5.114E-02	8.182E-04	3.474E-02	8.670E-02	2.074E-01	3.701E-03	2.638E-05	1.879E-05
27.00	5.951E-22	1.480E-03	4.906E-02	7.840E-04	3.392E-02	8.376E-02	2.020E-01	3.622E-03	2.550E-05	1.817E-05
28.00	1.022E-22	1.471E-03	4.707E-02	7.513E-04	3.311E-02	8.093E-02	1.967E-01	3.544E-03	2.466E-05	1.757E-05
29.00	1.756E-23	1.460E-03	4.515E-02	7.200E-04	3.231E-02	7.819E-02	1.916E-01	3.467E-03	2.384E-05	1.698E-05
30.00	3.016E-24	1.447E-03	4.332E-02	6.899E-04	3.154E-02	7.555E-02	1.865E-01	3.392E-03	2.305E-05	1.642E-05


CHRONIC INHALATION INTAKE - Thorium-234
ARBITRARY UNIT INTAKE RATE (day^{-1})
1.0 MICRON PARTICULATE
100% Class Y
100% Class W
LUNG BURDEN (Arbitrary units)
1
2
3
4
5
6
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
TIME POST ONSET OF INTAKE (days)

CHRONIC INHALATION INTAKE - Thorium-234



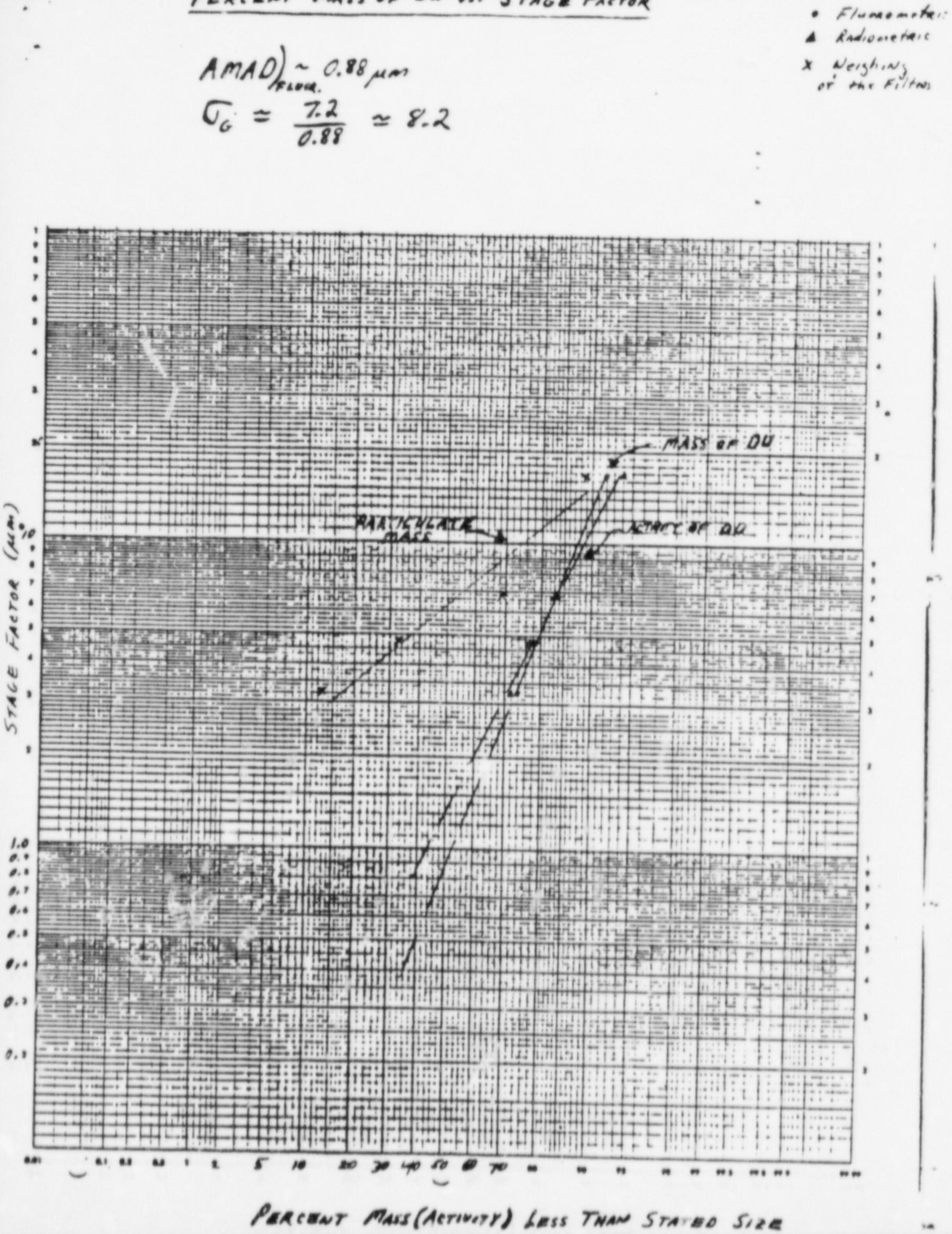


CHRONIC INHALATION INTAKE - Thorium - 234
ARBITRARY UNIT INTAKE RATE (day⁻¹)
1.0 MICRON PARTICULATE
100% Class W
INSTANTANEOUS URINE CONCENTRATION (arbitrary units/Liter) (10⁻³)
7
6
5
4
3
2
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
TIME POST ONSET OF INTAKE (days)

PERCENT MASS OF DU vs. STAGE FACTOR

$AMAD)_{FLUOR.} \sim 0.88\ \mu m$

$\sigma_G \simeq \frac{7.2}{0.88} \simeq 8.2$



10 CFR 20 MPC_a FOR DU AND TH-234

General Review

The current 10 CFR 20 MPC_a's for DU and Th-234 and respective regulatory limits are examined below. The specific activity (SA) of DU (a mixture of U-238, U-235 and U-234) used is 4.5×10^{-7} Ci/gram. This has been confirmed by recent independent mass, alpha and gamma spectroscopic analysis of several depleted UF_4 samples. The above value is also consistent with the equation: SA = 0.338 + 0.477E; where, E = wt.% U-235 (in this case, E = 0.24). Using the above SA, the 10 CFR 20.103 quarterly breathing rate of 6.3×10^8 ml/quarter, and the 10 CFR 20, Appendix B, Footnote 4, 0.2 mg/m^3 restriction on chemical toxicity; the MPC_a and Intake Limits can be calculated as follows:

Appendix B, Table I Values

MPC_a DU (S)

$$\frac{0.2\ mg}{m^3} \times \frac{1\ m^3}{10^6 cm^3} \times \frac{cm^3}{ml} \times \frac{10^3\ \mu g}{mg} \times \frac{4.5 \times 10^{-7}\ \mu Ci}{\mu g} = 1 \times 10^{-10}\ \mu Ci/ml$$

(Note: 8×10^{-3} $(4.5 \times 10^{-7}) = 3.6 \times 10^{-9}$; $< 4 \times 10^{-9}$ µCi-hr/ml limit)

MPC_a DU (I)

(Note: Same for U-238, U-235 and U-234)	1×10^{-10} µCi/ml
MPC_a Th-234 (S)	6×10^{-8} µCi/ml
MPC_a Th-234 (I)	3×10^{-8} µCi/ml

Summary of Intake Limits

Material	8 MPC-hr	40 MPC-hr	520 MPC-hr	Seven Working Day Intake Rate
DU (S)	8.72×10^{-4} µCi (1.94 mg)	4.36×10^{-3} µCi (9.68 mg)	5.66×10^{-2} µCi (126 mg)	(1.38 mg/day)
DU (I)	8.72×10^{-4} µCi (1.94 mg)	4.36×10^{-3} µCi (9.68 mg)	5.66×10^{-2} µCi (126 mg)	(1.38 mg/day)
Th-234 (S)	0.58 µCi	2.90 µCi	37.8 µCi	0.41 µCi/day
Th-234 (I)	0.29 µCi	1.45 µCi	18.9 µCi	0.21 µCi/day

NMI AIR SAMPLING PROGRAM

General Review

Air sampling for alpha emitting DU and respective beta emitting daughter products is a very sensitive method for estimating intakes. The approach taken is that of low volume air sampling through a glass fiber filter (typically at 2 to 3 liters per minute), a 48 hour decay period (i.e., for Rn-222 daughter products), and subsequent gross alpha and gross beta counting with an automatic low background proportional counting system. All alphas are assumed to arise from DU and all betas from Th-234. This is believed to be conservative in that some residual radon daughter and/or thoron daughter alpha activity may be present (i.e., with long sampling times) and at least two apparent betas arise from Th-234 (i.e., from 1.17 minute $T_{\frac{1}{2}}$ Pa-234m). Typical low limits of detection for DU and daughter products using Regulatory Guide 4.14 formalism are as follows:

$$LLD = \frac{4.65\ S_b}{2.22 \times 10^6\ \text{dpm}/\mu\text{Ci}\ \ E\ V\ Y\ \ \exp(-\lambda \Delta t)}$$

Where,	LLD	is the lower limit of detection (µCi/ml)
	S_b	is the standard deviation of the background rate (with a 5 minute count typically 0.35 cpm alpha, 1.1 cpm beta)
	E	is the efficiency (typically 0.35 c/d alpha, 0.45 c/d beta)
	V	is the sample volume (milliliters - variable)
	Y	is the fractional yield (i.e., self absorption 0.7 alpha, 1.0 beta)
	$\exp(-\lambda \Delta t)$	is the decay correction (none alpha, generally negligible beta)

	0.5 hours	1.0 hours	8.0 hours
LLD DU (µCi/ml)	5×10^{-11}	3×10^{-11}	3×10^{-12}
LLD Th-234 (µCi/ml)	9×10^{-11}	4×10^{-11}	5×10^{-12}

Stationary Samplers

Stationary air samplers are located throughout the plant to monitor the general working environs. Also, locations are chosen in an attempt to evaluate specific operator's positions relative to equipment or processes. Sample filters are changed on shift bases (three shifts maximum) to minimize loading. Additionally, fixed Personal Air Monitors (PAM's) are often used to evaluate operations. Data is compiled, reviewed daily, and averaged quarterly to monitor trends and guide the Bioassay Program. Attached is our 1983 Summary of Quarterly Averages.

Personal Samplers

Personal Air Monitors (PAM's) are used throughout the plant to specifically monitor the breathing zone air quality. They are used integrally in the NMI Radiation Work Permit (RWP) Program. That is, if any non-routine operation has any likelihood of generating airborne DU, a PAM is required. Also, characterized routine operations where the DU solubility is uncertain or unsupported Th-234 may be present (i.e., Foundry), enhanced issuance of PAM's is the standard operating procedure (typically one PAM per week). In these cases, an Intake Method (see Regulatory Guide 8.30) is used to monitor compliance with 10 CFR 20.103. Attached are the forms currently used for tracking employees' intake. For routine operations, estimates of intakes are considered for periods when a PAM is not being worn. Non-routine operations/intakes are tracked on an "event" basis. This is justified in that the personnel involved in this scenario are generally in the Maintenance Department. Intakes occurring during their normal activities (i.e., equipment maintenance not requiring a Special RWP) would be well less than ten percent (10%) of the limit as indicated by the stationary summaries. Thus, the intake need not be included (10 CFR 10.103 a3).

It is important to note at this point that various forms of respiratory protection are used in conjunction with our RWP Program. This is consistent with the ALARA philosophy. However, the Respiratory Protection Program is not formal, and no protection factor credit is used in estimating intakes. Furthermore, respiratory protection does not replace engineering controls which are also an integral part of our ALARA philosophy.

NUCLEAR METALS: 1983 AIR QUALITY SUMMARY

STATIONARY SAMPLING *

	1ST QUARTER		2ND QUARTER		3RD QUARTER		4TH QUARTER	
AREA	ALPHA	BETA	ALPHA	BETA	ALPHA	BETA	ALPHA	BETA
CAF LINE	.02	<.01	.02	<.01	.01	<.01	.01	<.01
FOUNDRY	.03	.03	.02	.02	.01	.01	.03	.02
1400 TON PRESS	.03	.01	.01	.01	.01	.01	.02	.01
MACHINE SHOP	.05	<.01	.06	<.01	.04	<.01	.03	<.01
M.S. ANNEX	.01	<.01	.01	<.01	.01	<.01	.01	<.01
MEZZANINE	.01	<.01	.02	<.01	.01	<.01	.01	<.01
REDUCTION	.12	.01	.03	.01	-	-	-	-
RED. OVENS	.12	.01	.08	.01	-	-	-	-
LIMIT	1.00	3.00	1.00	3.00	1.00	3.00	1.00	3.00

* AVERAGE QUARTERLY RESULTS (ALPHA μCi E-10/ml and BETA μCi E-8/ml)

SAMPLE FORM

EMPLOYEE BREATHING ZONE: QUARTERLY AIR SAMPLE RESULTS

NAME: ______________________ EMPLOYEE ID #: ______ DEPT: _____

S ①	19__ DATE	D ②	LOCATION	ALPHA $\left(\frac{\mu Ci}{ml} \times 10^{-10}\right)$ (A)	TIME (Min) (T)	ESTIMATED INHALED URANIUM ($\mu Ci \times 10^{-2}$)			
						SAMPLE $\left(\frac{A \times T}{5000}\right)$	RUNNING TOTAL (RT)	ESTIMATED UPDATE $\left(RT \times \frac{D}{S}\right)$	QUARTERLY PROJECTION $\left(E.\ Up. \times \frac{65}{S}\right)$
	Guide			1.0		0.087		5.66	

① S = Sample Number. ② D = Number of workdays elapsed in Quarter.
For those not wearing PAM on routine basis, D/S = 1.
Quarterly projection performed on a 'spot check' basis.

H.P. Form No. 19, Revised: December 9, 1982.

(SAMPLE FO: m

EMPLOYEE BREATHING ZONE: QUARTERLY AIR SAMPLE RESULTS

NAME: ____________________ EMPLOYEE ID #: __________ DEPT: ______

S	19__ DATE	D	LOCATION	BETA $\left(\frac{\mu Ci}{ml} \times 10^{-8}\right)$ (A)	TIME (Min) (T)	ESTIMATED INHALED Th-234 (µCi) SAMPLE $\left(\frac{A \times T}{5000}\right)$	RUNNING TOTAL (RT)	ESTIMATED UPDATE $\left(RT \times \frac{D}{S}\right)$	QUARTERLY PROJECTION $\left(E. Up. \times \frac{65}{D}\right)$
	Guide			3.0		0.29			18.88

S = Sample Number. D = Number of workdays elapsed in Quarter.
For those not wearing PAM on routine basis, D/S = 1.
Quarterly projection performed on a 'spot check' basis.
H.P. Form No. 19, Revised: December 9, 1983.

SAMPLE FORM

EMPLOYEE BREATHING ZONE: SEVEN DAY AIR SAMPLE RESULTS

NAME: ______________________ EMPLOYEE ID #: ____________ DEPT: ______

40 MPC-hr Check

NOTE: The NRC states that intakes shall be kept ALARA and restricts intakes in any seven (7) consecutive days to that which would result from an exposure at the MPC_a for forty (40) hours (10 CFR 20.103 b2). Any estimated inhaled uranium or thorium-234 result in excess of eight (8) MPC-hours shall prompt completion of this worksheet and a check by a Health Physics staff member. Estimates in excess of forty (40) MPC-hours shall be investigated by a Health Physics staff member (see 10 CFR 20.103).

Nuclide	8 MPC-hr	40 MPC-hr
Uranium	0.087×10^{-2} µCi	0.436×10^{-2} µCi
Th-234	0.29 µCi	1.45 µCi

DAY	DATE	URANIUM ($\times 10^{-2}$) µCi	Th-234 µCi
1			
2			
3			
4			
5			
6			
7			
TOTAL			

Radionuclide Mixture Check

NOTE: For the Foundry Area where Th-234 is unsupported, the following condition must be checked.

$$\frac{\text{7 Day Total Uranium}}{\text{40 MPC-hr}} + \frac{\text{7 Day Total Th-234}}{\text{40 MPC-hr}} \leq 1$$

$$\frac{\_\_\_\_\_\_}{0.436 \times 10^{-2}\ \mu Ci} + \frac{\_\_\_\_\_\_}{1.45\ \mu Ci} = \square$$

H.P. Form No. 19, Revised December 9, 1983

NMI URINALYSIS PROGRAM

General Review

The fluorometric determination of uranium in urine has been generally accepted as one of the most sensitive and practical methods for some time. The method is well described by the American Society for Testing and Materials procedure No. D2907-75. Limits of detection with only several milliliters of solution are typically 1 µg/l. This indicates an ability to "see" 1 µg of uranium in a twenty-four (24) hour urine collection using a chemical separation (i.e., ion exchange or organic extraction).

The Urinalysis Program can be described as having three (3) main functional aspects as follows:

1). Baseline Evaluations

This aspect involves mainly a pre-employment evaluation of uranium urine excretion levels via spot sampling. Attached is a histogram of the results of a number of pre-employment urine concentration measurements. The mean value (about 5 µg/l) and range is consistent with the observations of others (see Wing, J.F., Health Physics, Vol. 11, pp. 731-735).

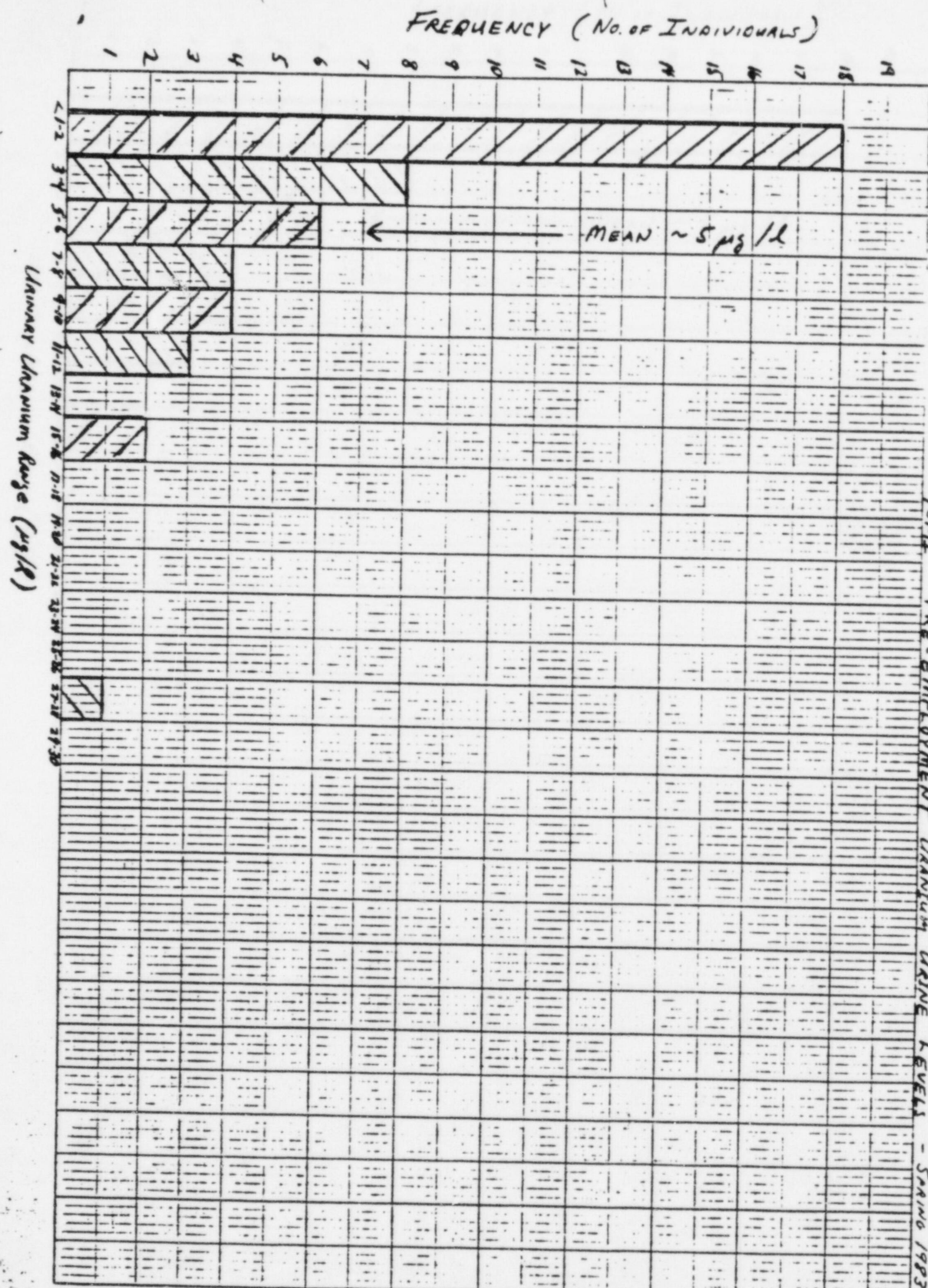
2). Exposure Control Evaluations

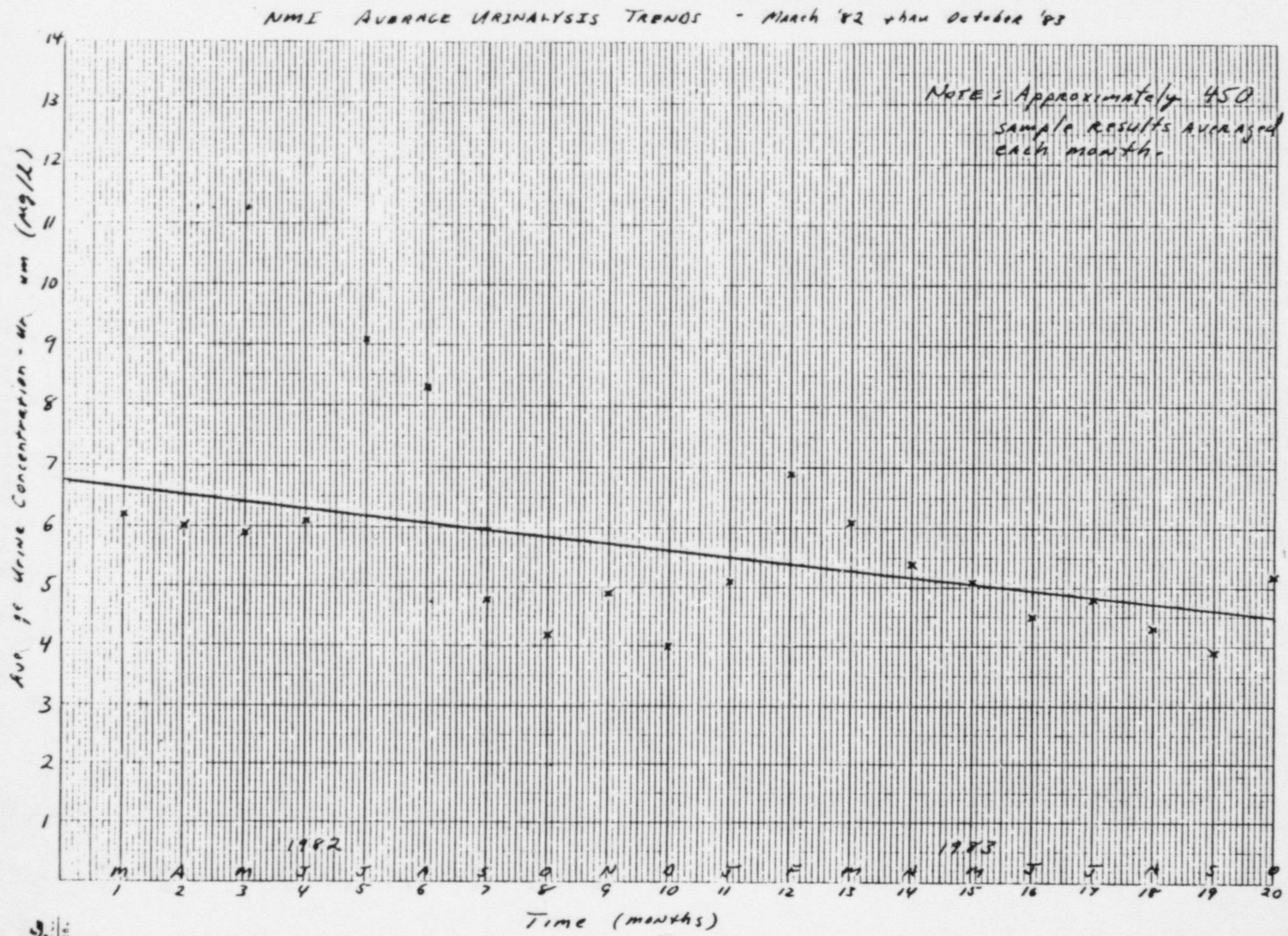
Routinely, samples are required from all employees working in restricted areas. The intent is to assure that engineering controls and the Air Sampling Program are effective in maintaining chronic exposures ALARA. Based on current urine trends (see attachment), air sampling results, the metabolic models for uranium and the supported assumption that there is some fraction of soluble uranium in most (if not all) of the plant areas; it is felt that the current monthly frequency required for all employees routinely working in restricted areas (i.e., chronic exposure) is justified.

3). Diagnostic Evaluations

When air sampling (stationary or PAM) results, urinalysis and/or an unusual event indicates that the potential existed for a significant intake, diagnostic evaluations are initiated. These most often involve spot urinalysis with daily or weekly frequency but are not so limited. The metabolic models for 100% Class Y uranium or thorium indicate poor sensitivity with spot urines. However, twenty-four (24) hour urines, lung counting, and/or fecal analysis is applicable.

As stated above, it is felt that there is some fraction of soluble uranium in our air contaminant. Attached is a Battelle report regarding an evaluation of aerosol solubility from a DU grinding operation. A classification of 56% D and 44% Y was recommended. This classification was recently used in a diagnostic evaluation of a machining aerosol intake (see attached memo to the Record). The agreement between the model and observed excretion was quite good. Others have observed a similar degree of solubility during controlled DU ammunition test firings (see Pacific Northwest Laboratory Report No. PNL-2944, UC-35, November 1979). The diagnostic evaluation of a soluble DU acute intake above was able to detect approximately two (2) MPC-hours using urinalysis.


FREQUENCY (No. OF INDIVIDUALS)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
MEAN ~5 µg/l
Urinary Uranium Range (µg/l)
<1-2 3-4 5-6 7-8 9-10 11-12 13-14 15-16 17-18 19-20 21-22 23-24 25-26 27-28 29-30
NMI PRE-EMPLOYMENT URANIUM URINE LEVELS - SPRING 1983



20 Squares to the Inch

NOV 15 1982

FRANK T. VUMBACO

Battelle
Pacific Northwest Laboratories
P.O. Box 999
Richland, Washington U.S.A. 99352
Telephone (509)
Telex 15-2874

November 4, 1982

Mr. David Allard
Nuclear Metals Inc.
Concord, Massachusetts 01742

Dear Mr. Allard:

FINAL REPORT ON THE STUDY: DISSOLUTION-RATE CLASSIFICATION OF URANIUM IN AN AIRBORNE DUST SAMPLE, BNW CONTRACT NO. 23112005339

The purpose of this study was to conduct dissolution trials on the airborne dust sample that you delivered to us on August 9, 1982 and to classify the dissolution rate of uranium from this sample in terms of the ICRP Task Group lung model. The sample was received as a deposit of dust on a Millipore filter and was divided into two portions. One portion was the dust that could be easily scraped off the filter surface with a stainless steel scalpel and was designated NM-P. The other portion was the dust that remained imbedded on the filter and was designated NM-F.

The dissolution behavior of each portion was determined by the "mini-batch" method described on page 10 of the U.S. Nuclear Regulatory Commission document, "Solubility Classification of Airborne Uranium Products from LWR-Fuel Plants," NUREG/CR-1428, that I sent you earlier. Portion NM-P was suspended in 2.00 ml of stirred simulated lung fluid contained in a 3-ml, conical-bottom vial (Pierce Chemical, Reacti-Vial) whereas portion NM-F was placed in a 5-ml, conical-bottom vial with the imbedded particles facing 5.00 ml of stirred simulated lung fluid. The temperature of the systems was maintained at 37 $\pm$ 1°C, and the amounts of uranium that dissolved from the portions into simulated lung fluid after various periods of time up to 60 days were measured by ASTM procedure D2907-75, Method B (1982 Annual Book of ASTM Standards, Part 45, Nuclear Standards, American Society for Testing and Materials, Philadelphia). At the end of 60 days, the undissolved uranium in each vial was measured; and the initial amount of uranium in each portion was calculated as the sum of the dissolved and undissolved amounts. The fraction, F, of uranium remaining undissolved after time t was computed and these data were used to obtain the best statistical fit to equations of the form:

$$F = \Sigma_i f_i \exp(-0.693t/T_i)$$

Battelle

where the f_i are the fractions of the total uranium in each portion dissolving with half-time T_i. The values of f_i and T_i were then used to classify the uranium in the portions according to the percentages of D, W and Y components, as defined by the ICRP Task Group (Health Phys., 12: 173-206, 1966).

The total amount of uranium found in portion NM-P was 38.3 μg, and the total amount of uranium found in portion NM-F was 142.0 μg. Based on these total weights and the amounts of uranium dissolved after various periods of time, values of F were calculated and are shown in Table 1.

TABLE 1. Fraction of Uranium Remaining Undissolved as a Function of Time

Portion NM-P		Portion NM-F	
t	F	t	F
0.00d	1.000	0.00d	1.000
0.10	0.647	0.10	0.548
0.22	0.638	0.22	0.506
1.00	0.633	1.00	0.478
3.20	0.623	3.00	0.464
10.00	0.494	10.00	0.456
21.00	0.440	21.00	0.451
38.00	0.413	38.00	0.446
60.00	0.411	60.00	0.440

Approximate values for the f_i and T_i were obtained by graphical analysis of the data, and these were used as starting values in an iterative computer program (Subroutine NREG from the Madison Academic Computing Center) to obtain the best fit to the data by regression analysis. The resulting values and dissolution-rate classifications are shown in Table 2.

Battelle

TABLE 2. Uranium Dissolution-Rate Parameters and Classifications

Portion	f_i	τ_i	f_2	τ_2	f_3	τ_3	Classification
NF-P	0.34	0.01d	0.25	7.8d	0.41	20,000d	59%D, 41%Y
NF-F	0.48	0.03d	0.05	0.7d	0.47	888d	53%D, 47%Y

The short-term dissolution patterns for the two portions of the sample were different, probably reflecting the differences in their configuration. However, since the ICRP model assigns a D classification to all material with a dissolation half-time of 10 days or less, the overall classifications of the portions agree fairly well. An average classification of 56%D, 44%Y for the uranium in the sample is recommended for use with the ICRP Task Group lung model.

Sincerely,

Donald R. Kalkwarf

Donald R. Kalkwarf, Ph.D.
Chemical Methods and Kinetics
Biology and Chemistry Department

OFFICE MEMORANDUM

Nuclear Metals Inc.

to: The Record

date: 12-30-83

from: D. J. Allard DJA

subject: INTAKE EVALUATION

Background:

On 12-12-83, "B" Shift personnel resumed DU machining operations in the CAF Line after a period of time when this machinery had been non-operational. Apparently, the ventilation had been shut down and machining proceeded for several hours under these conditions. Once the situation was realized, the area was shutdown by Health Physics and an evaluation was begun. All personnel involved were instructed to submit spot urine samples for the next four days.

Results:

Initial air sample results indicated exposures on the order of two (2) MPC-hours. No one was restricted from further work. On 12-29-83 our MIT consultant phoned in the emergency results. One individual [redacted] exceeded our current 60 ug/l urinary uranium investigation level. His results are as follows:

Date	Time	Days Post Intake	ug/l	Est. σ
12-12-83	12:00 Midnight	0.25	67	8.2
12-13-83	12:00 Midnight	1.25	14	3.7
12-14-83	12:00 Midnight	2.25	8	2.8
12-15-83	12:00 Midnight	3.25	8	2.8
12-16-83	12:00 Midnight	4.25	6	2.4

Assuming an acute inhalation and the ICRP 30 Uranium Model (see attached calculations), an estimated intake of two (2) to four (4) MPC-hours is obtained from the above urine data. Additionally, the model assumptions used agree well with the observed urine data.

Action:

Spoke to Nancy Dennis (NRC Region I) today and informed her of the reported result in excess of our investigation limit, the apparent cause of the intake, and our evaluation of the intake.

Recommendation:

Facilities Department evaluate audio or visual indicators of equipment ventilation status.

DJA:swk

Attachments

CC: AR Gilman, FJ Vumbaco, KP Fogarty, Individual's File

CALCULATIONS: CAF Machine Operator's Intake on 12/12/83.

Estimate based on area air sampling results

$$3.5\ \text{hr} \times 0.5\times10^{-10}\ \frac{\mu Ci}{ml} \times \frac{1\ \text{MPC}_a}{1\times10^{-10}\ \mu Ci/ml} = \boxed{1.8\ \text{MPC-hr}}$$

Estimate based on 0.25 day urine data

$$\frac{1\ \text{mg intake}}{\langle 71\ \mu g/l\rangle_{urine}} = \frac{x\ \text{mg}}{67\ \mu g/l} \qquad x = 0.94\ \text{mg}$$

$$\frac{40\ \text{MPC-hr}}{9.68\ \text{mg}} = \frac{x\ \text{MPC-hr}}{0.94\ \text{mg}} \qquad x = \boxed{3.9\ \text{MPC-hr}}$$

Estimate based on 1.0 day urine data

$$\frac{1\ \text{mg intake}}{\langle 41.78\ \mu g/l\rangle_{urine}} = \frac{x\ \text{mg}}{19.04\ \mu g/l} \qquad x = 0.46\ \text{mg}$$

$$\frac{40\ \text{MPC-hr}}{9.68\ \text{mg}} = \frac{x\ \text{MPC-hr}}{0.46\ \text{mg}} \qquad x = \boxed{1.9\ \text{MPC-hr}}$$

Note: The ICRP 30 Model is not as accurate for short team urinary clearance as it is for long term. In this regard, the estimate based on the expected 1.0 day urine level is no doubt the better of the two.

Individual's Urine Data Fit to obtain expected urine level at 1.0 days.

```
                    CLX
              XROM "ΣPOW"
ΣPOW
days → .25   ENTER↑
µg/l → 67.00 XEQ A
       1.25  ENTER↑
       14.00 XEQ A
       2.25  ENTER↑
       8.00  XEQ A
       3.25  ENTER↑
       8.00  XEQ A
       4.25  ENTER↑
       6.00  XEQ A
             FIX 4
             XEQ E
R2=0.9799
a=19.0359
b=-0.8521
       .2500   RUN
Y.=62.0320
       1.2500  RUN
Y.=15.7395
       2.2500  RUN
Y.=9.5381
       3.2500  RUN
Y.=6.9722
       4.2500  RUN
Y.=5.5474

       1.0000  RUN
Y.=19.0359
       2.0000  RUN
Y.=10.5451
       3.0000  RUN
Y.=7.4644
       4.0000  RUN
Y.=5.8416
       5.0000  RUN
Y.=4.8300
       6.0000  RUN
Y.=4.1350
```

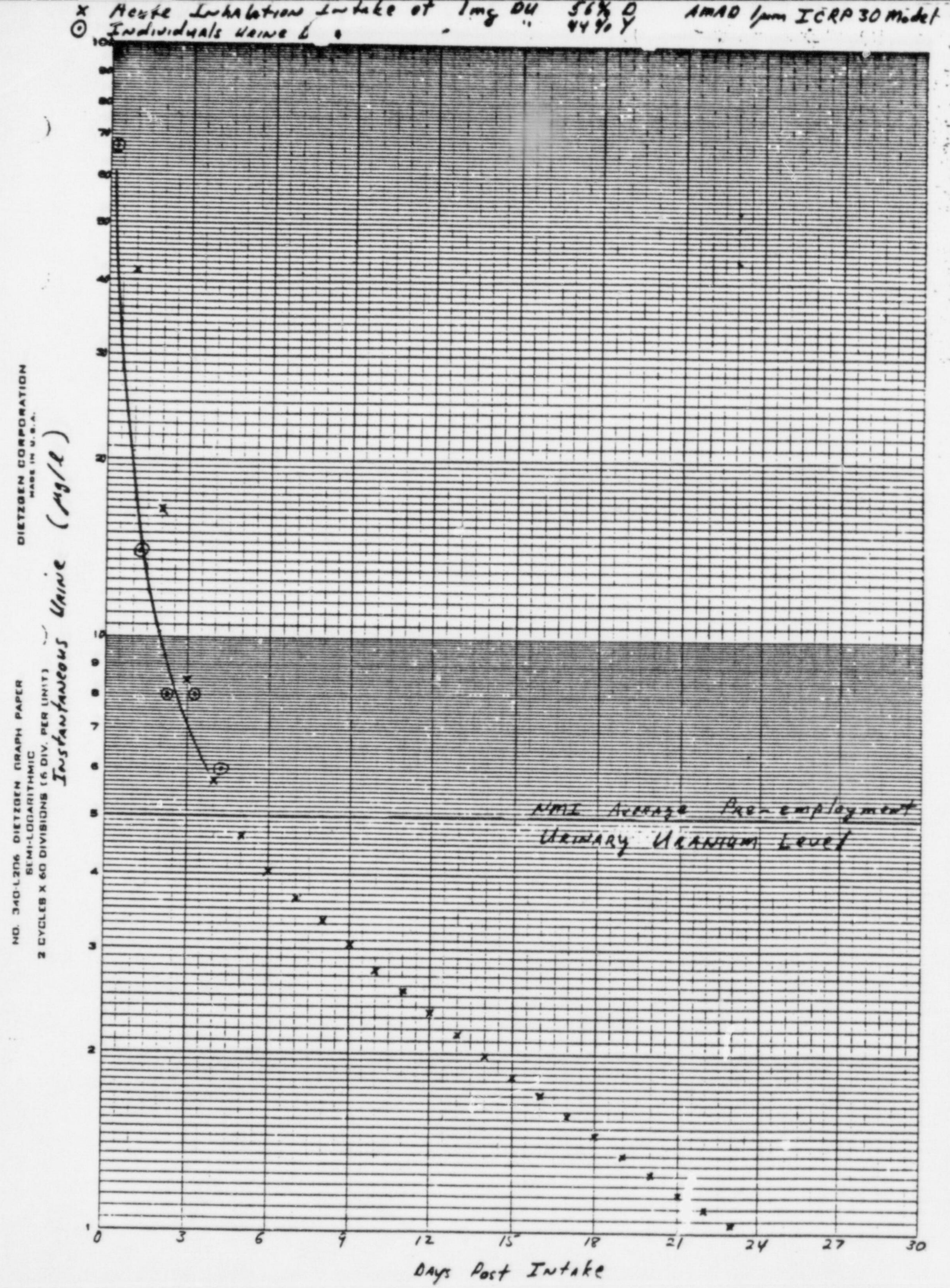
$\langle Y \rangle = a x^b$

Fit of ICRP 30 Model data for 1 mg intake to obtain expected urine level at 0.25 days.

```
              XROM "ΣPOLYC"
ΣPOLYC
       1.00  ENTER↑
       41.78 XEQ A
       2.00  ENTER↑
       16.46 XEQ A
       3.00  ENTER↑
       8.528 XEQ A
       4.00  ENTER↑
       5.769 XEQ A
       5.00  ENTER↑
       4.651 XEQ A
       6.00  ENTER↑
       4.061 XEQ A
             FIX 4
             XEQ E
R2=0.9957
a=83.5130
b=-53.1964
c=11.9207
d=-0.8787
```

$\langle Y \rangle = a + bx + cx^2 + dx^3$

```
       .2500   RUN
Y=70.9452
       1.0000  RUN
Y=41.3586
       2.0000  RUN
Y=17.7738
       3.0000  RUN
Y=7.4864
       4.0000  RUN
Y=5.2246
       5.0000  RUN
Y=5.7162
       6.0000  RUN
Y=3.6894
```


x Acute Inhalation Intake of 1mg DU 56% D AMAD 1μm ICRP 30 Model
⊙ Individuals Urine " 44% Y
Instantaneous Urine (μg/l)
Days Post Intake
NMI Average Pre-employment Urinary Uranium Level
0
3
6
9
12
15
18
21
24
27
30
1
2
3
4
5
6
7
8
9
10
20
30
40
50
60
70
80
90
100
NO. 340-L206 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
2 CYCLES X 60 DIVISIONS (6 DIV. PER UNIT)
DIETZGEN CORPORATION
MADE IN U.S.A.

URANIUM 238
ACUTE INHALATION INTAKE 1.000E+00 mg
56.0% CLASS D 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 5.000E-02
44.0% CLASS Y 1.0 MICRON PARTICULATE FRACTION FROM GI TO SYSTEMIC (F1)= 2.000E-03

SYSTEMIC RETENTION EQUATION PARAMETERS

COMPARTMENT	COEFFICIENT	HALFLIFE(DAYS)
1	5.360E-01	2.500E-01
2	2.400E-01	6.000E+00
3	2.000E-01	2.000E+01
4	1.040E-03	1.500E+03
5	2.300E-02	5.000E+03

FRACTION EXCRETED IN URINE(FU)= 1.000E+00 FRACTION OF INTAKE DEPOSITED IN BODY= 0.630
PHYSICAL HALF LIFE= 1.650E+12 DAYS TIME INTERVAL FOR INCREMENTAL URINE SAMPLES= 1.000E+00 DAYS

DAYS POST INTAKE	NASAL BURDEN mg	LYMPH BURDEN mg	LUNG BURDEN mg	GI BURDEN mg	SYSTEMIC BURDEN mg	TOTAL BURDEN mg	ACCUMULATED FECES mg	ACCUMULATED URINE mg	INCREMENTAL URINE mg	INSTANTANEOUS URINE mg /L
1.00	2.310E-02	9.727E-03	1.390E-01	1.944E-01	1.181E-01	4.516E-01	4.539E-02	1.100E-01	1.100E-01	4.178E-02
2.00	4.084E-03	4.898E-03	9.326E-02	1.268E-01	1.122E-01	3.322E-01	1.466E-01	1.472E-01	3.721E-02	1.646E-02
3.00	7.219E-04	1.888E-03	7.669E-02	6.460E-02	1.053E-01	2.466E-01	2.190E-01	1.637E-01	1.649E-02	8.528E-03
4.00	1.276E-04	6.976E-04	7.033E-02	3.032E-02	9.847E-02	1.991E-01	2.574E-01	1.734E-01	9.693E-03	5.769E-03
5.00	2.256E-05	3.033E-04	6.772E-02	1.391E-02	9.212E-02	1.737E-01	2.757E-01	1.806E-01	7.193E-03	4.651E-03
6.00	3.988E-06	1.933E-04	6.656E-02	6.410E-03	8.630E-02	1.593E-01	2.841E-01	1.866E-01	6.065E-03	4.061E-03
7.00	7.050E-07	1.756E-04	6.599E-02	3.015E-03	8.098E-02	1.500E-01	2.880E-01	1.920E-01	5.387E-03	3.653E-03
8.00	1.246E-07	1.863E-04	6.569E-02	1.466E-03	7.613E-02	1.433E-01	2.898E-01	1.969E-01	4.876E-03	3.322E-03
9.00	2.203E-08	2.053E-04	6.551E-02	7.502E-04	7.170E-02	1.380E-01	2.907E-01	2.013E-01	4.446E-03	3.035E-03
10.00	3.895E-09	2.268E-04	6.539E-02	4.145E-04	6.765E-02	1.334E-01	2.912E-01	2.054E-01	4.066E-03	2.778E-03
11.00	6.885E-10	2.489E-04	6.529E-02	2.548E-04	6.393E-02	1.295E-01	2.914E-01	2.091E-01	3.726E-03	2.548E-03
12.00	1.217E-10	2.712E-04	6.521E-02	1.780E-04	6.052E-02	1.259E-01	2.916E-01	2.125E-01	3.420E-03	2.341E-03
13.00	2.151E-11	2.935E-04	6.514E-02	1.407E-04	5.738E-02	1.227E-01	2.917E-01	2.157E-01	3.145E-03	2.154E-03
14.00	3.803E-12	3.158E-04	6.507E-02	1.224E-04	5.449E-02	1.197E-01	2.917E-01	2.186E-01	2.896E-03	1.986E-03
15.00	6.723E-13	3.380E-04	6.500E-02	1.133E-04	5.183E-02	1.169E-01	2.918E-01	2.213E-01	2.671E-03	1.833E-03
16.00	1.189E-13	3.601E-04	6.493E-02	1.088E-04	4.937E-02	1.144E-01	2.919E-01	2.237E-01	2.468E-03	1.695E-03
17.00	2.101E-14	3.823E-04	6.486E-02	1.064E-04	4.709E-02	1.121E-01	2.919E-01	2.260E-01	2.284E-03	1.570E-03
18.00	3.714E-15	4.044E-04	6.480E-02	1.052E-04	4.498E-02	1.099E-01	2.920E-01	2.281E-01	2.117E-03	1.456E-03
19.00	6.566E-16	4.264E-04	6.473E-02	1.045E-04	4.302E-02	1.079E-01	2.921E-01	2.301E-01	1.966E-03	1.353E-03
20.00	1.161E-16	4.484E-04	6.466E-02	1.041E-04	4.120E-02	1.060E-01	2.921E-01	2.319E-01	1.828E-03	1.260E-03
21.00	2.052E-17	4.703E-04	6.459E-02	1.038E-04	3.951E-02	1.042E-01	2.922E-01	2.336E-01	1.703E-03	1.174E-03
22.00	3.627E-18	4.922E-04	6.453E-02	1.036E-04	3.793E-02	1.026E-01	2.922E-01	2.352E-01	1.589E-03	1.097E-03
23.00	6.412E-19	5.141E-04	6.446E-02	1.034E-04	3.645E-02	1.010E-01	2.923E-01	2.367E-01	1.485E-03	1.026E-03
24.00	1.133E-19	5.359E-04	6.439E-02	1.033E-04	3.507E-02	9.956E-02	2.924E-01	2.381E-01	1.390E-03	9.609E-04
25.00	2.004E-20	5.577E-04	6.433E-02	1.031E-04	3.377E-02	9.820E-02	2.924E-01	2.394E-01	1.303E-03	9.016E-04
26.00	3.542E-21	5.794E-04	6.426E-02	1.030E-04	3.256E-02	9.692E-02	2.925E-01	2.406E-01	1.224E-03	8.472E-04
27.00	6.262E-22	6.011E-04	6.419E-02	1.028E-04	3.141E-02	9.571E-02	2.925E-01	2.418E-01	1.151E-03	7.973E-04
28.00	1.107E-22	6.227E-04	6.413E-02	1.027E-04	3.034E-02	9.457E-02	2.926E-01	2.428E-01	1.084E-03	7.514E-04
29.00	1.957E-23	6.443E-04	6.406E-02	1.026E-04	2.932E-02	9.349E-02	2.926E-01	2.439E-01	1.022E-03	7.091E-04
30.00	3.459E-24	6.659E-04	6.399E-02	1.024E-04	2.837E-02	9.246E-02	2.927E-01	2.448E-01	9.650E-04	6.701E-04

DNP=0.300 DTB=0.080 DP=0.250 TOTAL DEPOSITION IN BODY= 0.630

ATOMS BALANCE FOR ALL TIMES = 0.630000

NMI ANNUAL LUNG COUNTING

General Review

The selection of employees for lung counting is done by reviewing each department for those individuals with the highest uranium urine and/or Personal Air Monitoring (PAM) result during the previous year. Additionally, all Foundry employees are asked to participate. In 1983 in excess of one hundred persons were lung counted (> 20% of the exposed work force) representing a cross-section of the employee population by Department (i.e., plant area).

Attached is a supplementary letter and standard report preface to our 1983 lung counting from our vendor. It should be noted that the method for deriving in vivo DU burdens involves direct measurement of Th-234 and assumes equilibrium with U-238. The photons counted are the 63 and 93 KeV gamma rays. Our vendor states that "the typical lower limit of detection for Th-234 is 0.6 to 1.0 nanocuries, which is equivalent to 2 to 3 mg of natural uranium." Twenty-one percent (21%) of our 1983 counting results were in this range (see attached histogram). Recent conversations with our vendor indicate that an apparent burden of 3 mg DU is typical for anyone who has had recent exposure to Radon-222 daughter products (lead-214 can cause the greatest interference). It is felt that natural Rn-222 emanating indoors from building construction materials could be affecting the employee lung counts. If 3 to 4 mg of "apparent" DU is a typical result due to radon daughters, then fifty percent (50%) of the 1983 lung counts would be in this range.

Also included in the attached histogram is a distribution of the 1983 counting results for our Foundry employees. In this area we have documented levels of unsupported Th-234. As would be expected, these results are skewed to the high end of the distribution. If the result of the highest reported DU burden of 11.0 mg (for a Foundry employee) is interpreted as Th-234 activity, the burden would be equivalent to 3.7 nanocuries.

Annual lung counting occurs after plant shutdown in an attempt to monitor long-term burdens of DU. However, all those counted in 1983, except the Foundry personnel, were working prior to the measurement (several worked over the shutdown period). It is possible that short-term, rapidly clearing DU is being observed also.

Despite the above technical problems associated with lung counting for DU and possible skewing of results due to the employee selection process, it is felt that our vendor has adequate sensitivity to monitor long-term increases of slowly clearing burdens. Also, considering the burdens that the metabolic models would predict for chronic inhalation of insoluble DU and/or Th-234 at regulatory limits -- the lung counting results are quite reasonable and an annual frequency is justified.

HELGESON SS

HELGESON SCIENTIFIC SERVICES

5587 SUNOL BOULEVARD • PLEASANTON, CALIFORNIA 94566
(415) 846-3453 • TWX: 910 482 6460 • Cable Address: HELGENUC

Rec'd 10/11/83 David J Allard

September 30, 1983

Mr. Dave Allard
Nuclear Metals, Inc.
2229 Main Street
Concord, Massachusetts 01742

RE: In-Vivo Uranium Lung Count Results

Dear Mr. Allard:

Here is the corrected and expanded report of the Uranium lung counts performed over the period of July 18-22, 1983.

The error in our first report for this work has been corrected. The Depleted Uranium results are in units of milligrams; the first report erroneously indicated the activity units to be nanocuries.

Also in the corrected report we are reporting Th-234 results for selected individuals in Appendix II. The Th-234 activity is converted to equivalent milligrams of Depleted Uranium with the factor 1.0 mg. Depleted Uranium per 0.34 nanocurie of Th-234.

I think we have not adequately communicated how we estimate U-238 lung/chest burdens with in-vivo counting techniques. I am enclosing some additional information about it, which will be routinely incorporated into our Uranium lung count reports in the near future.

If you have any questions concerning this information, please do not hesitate to contact me.

Sincerely,

HELGESON SCIENTIFIC SERVICES

Jeffrey S. Guehring

Jeffrey S. Guehring
Corporate Health Physicist

JSG:jf

Enclosures

URANIUM-238 ANALYSIS

[illegible]
accounting for the effect of non-equilibrium Radium daughters, [illegible]
Uranium-238 activity may be estimated indirectly from either Th-234 or U-235 that are present in the subject's lung count gamma-ray spectrum. The indirect determination is necessary because U-238 does not emit measurable gamma rays as it decays (see Table I: "U-238 Decay Chain").

The Th-234 method is more sensitive than the U-235 method for depleted and Natural Uranium exposures, and it is independent of the degree of Uranium enrichment of the source material.

Th-234 Method:

Th-234 is the first daughter in the U-238 decay series, and it emits significant gamma rays at 63 and 93 keV. The equilibrium activity ratio of U-238 to Th-234 is 1.0 to 1.0 (Note: Th-234 will "grow-in" to 90% of its equilibrium activity in 80-81 days if the source was not at equilibrium; i.e., recently purified Uranium).

The typical lower limit of detection for Th-234 is 0.6-1.0 nanocuries, which is equivalent to 2 to 3 mg. of Natural Uranium.

U-235 Method:

The U-235 activity is estimated directly from its primary gamma ray of 185 keV. The U-238 activity can then be calculated based on the enrichment level of the source material.

The typical lower limit of detection for U-235 is 55-95 pico curies, which is equivalent to 3.5 to 6.5 mg. of Natural Uranium.

The Th-234 method offers better sensitivity for U-238 determination for exposures to depleted and Natural Uranium. However, Th-231 and Radium daughters - especially Pb-214 and Fr-223 - can "interfere" in the Th-234 photopeak measurement and cause the U-238 to be overestimated. The first Radium daughter product, Radon, is a very mobile gas, and does not remain near the source unless it is incapsulated. The Radon daughters are highly ionized solid particles that cling to dust, hair and clothing.

The normal basic procedures for minimizing the interference from Radon daughters include locating the counter away from source material, limiting counting subjects' exposure to Radon for several hours prior to their count, washing/showering immediately prior to the count, and donning clean clothing.

There are four basic methods for evaluating and/or minimizing the magnitude of Radium daughter interference in the Th-234 analysis:

1. Background Corrections - Simultaneous collection of subject and background spectrum is the most accurate and direct method for accounting for the effect of non-equilibrium Radium daughters when they are uniformly distributed as DECAY SERIES.

2. U-235 Analysis Method - The derived U-238 activities from the Th-234 and U-235 analysis will agree when there has been no significant Radium daughter interference, and Th-234 derived activities significantly greater than U-235 derived activities are usually the result of Radium daughter interference in the Th-234 analysis.

3. Sequential Counting - Radium daughters have a relatively short half life and can easily be detected by recounting the subject after one (or more) hours to allow the daughters to decay.

4. Excreta and Blood Analyses - It is reasonable to expect a degree of consistancy of results between different bioassay tests and techniques. Such evaluations are matters requiring professional judgement and normally are based on a careful review of all available information.

URANIUM-235 DECAY SERIES[1]

Nuclide	Half-Life	Gamma Rays (Less than 1% yield)[2]
92 U-235	7.1×10^{8} yr.	1) 144 keV - 10.5% 2) 185 keV - 54.0%
90 Th-231	25.6 hr.	1) 26 keV - 2% 2) 84 keV - 8%
91 Pa-231	3.43×10^{11} yr.	1) 27 keV - 6% 2) 240 keV - 6%
89 Ac-227	21.6 yr.	
↳ 1.2% 90 Th-227	18.2 day	
↳ 98.8% 87 Fr-223	22 min.	1) 50 keV - 40% 2) 80 keV - 13% 3) 234 keV - 4%
88 Ra-223	11.7 day	1) 199 keV - 10% 2) 270 keV - 10% 3) 330 keV - 6%
86 Rn-219	3.9 sec.	1) 272 keV - 9% 2) 401 keV - 5%
84 Po-215	1.8×10^{-3} sec.	
82 Pb-211		1) 405 keV - 3.4% 2) 427 keV - 1.8% 3) 832 keV - 3.4%
83 Bi-211	2.2 min.	
84 Po-211	0.5 sec.	
83 Pb-207	Stable	

[1] Branching Decay less than 1% not shown
[2] γ Per disintegration of U-235 at equilibrium

U-238 DECAY CHAIN[1]

Nuclide	Half-Life	Gamma Rays (less than 1% yield)[2]
92 U-238	4.51×10^{9} yr.	
90 Th-234	24.1 day	1) 63 keV - 3.8% 2) 93 keV - 5.4%
91 Pa-234	1.18 minutes	
92 U-234	2.48×10^{5} yr.	
90 Th-230	8.0×10^{4} yr.	
88 Ra-226	1622 yr.	1) 186 keV - 3.3%
86 Rn-222	3.83 day	
84 Po-218	3.05 minutes	
* 82 Pb-214	26.8 minutes	1) 53 keV - 1% 2) 242 keV - 7.5% 3) 352 keV - 37.6%
83 Bi-214	19.7 minutes	1) 609 keV - 41.2% 2) 1120 keV - 15.0% 3) 1765 keV - 15.9%
84 Po-214	1.65×10^{-4} sec.	
82 Pb-210	Stable	

[1] Branching less than 1% not indicated here

[2] % Yield - γ per disintegration of U-238 at equilibrium

* NOTE: See additional data regarding X-ray yields attached. DJA

Radioactive Decay Data Tables

A Handbook of
Decay Data for Application to
Radiation Dosimetry and Radiological
Assessments

David C. Kocher

Technical Information Center
U. S. Department of Energy

• ^{212}Bi β^- Decay (60.55 m 6) I(min) = 0.10%
%β^- Decay = 64.07 6
Feeds ^{212}Po
See also ^{212}Bi α Decay

Radiation Type	Energy (keV)	Intensity (%)	Δ(g-rad/μCi-h)
ce-K- 1	634.06 10	0.125 5	0.0017

3 weak e's omitted:
Ee(avg)=10367.5; ΣIe= 0.01%

Radiation Type	Energy (keV)	Intensity (%)	Δ(g-rad/μCi-h)
β⁻ 1 max	440 4		
avg	128.1 13	1.17 5	0.0032
β⁻ 2 max	567 4		
avg	170.3 14	0.43 3	0.0016
β⁻ 3 max	625 4		
avg	190.6 14	3.44 10	0.0140
β⁻ 4 max	733 4		
avg	228.7 15	2.61 7	0.0127
β⁻ 5 max	1519 4		
avg	530.7 17	8.0 3	0.0904
β⁻ 6 max	2246 4		
avg	831.6 17	48.4 3	0.857
total β⁻			
avg	717.3 21	64.1 5	0.979

1 weak β's omitted:
Eβ(avg)= 129.7; ΣIβ= 0.05%

Radiation Type	Energy (keV)	Intensity (%)	Δ(g-rad/μCi-h)
γ 1	727.17 10	11.8 3	0.183
γ 2	785.46 7	1.97 5	0.0329
γ 3	893.43 9	0.652 20	0.0124
γ 4	952.10 10	0.313 18	0.0064
γ 6	1078.62 10	0.95 3	0.0219
γ 7	1512.75 10	0.56 5	0.0179
γ 8	1620.62 10	2.75 10	0.0949
γ 9	1679.5 5	0.121 20	0.0043
γ 11	1806.0 5	0.20 4	0.0076

2 weak γ's omitted:
Eγ(avg)= 1074.0; ΣIγ= 0.03%

• ^{212}Po α Decay (2.98E−7 s 3) I(min) = 0.10%

Radiation Type	Energy (keV)	Intensity (%)	Δ(g-rad/μCi-h)
α 1	8784.90 12	100	18.71

• ^{213}Bi α Decay (45.65 m 5) I(min) = 0.10%
%α Decay = 2.16 11
Feeds ^{209}Tl
See also ^{213}Bi β^- Decay

Radiation Type	Energy (keV)	Intensity (%)	Δ(g-rad/μCi-h)
α 1	5549 10	0.16 4	0.0169
α 2	5870 6	2.00 11	0.250
γ 1	323.81 5	0.13 3	0.0005

• ^{213}Bi β^- Decay (45.65 m 5) I(min) = 0.10%
%β^- Decay = 97.84 11
Feeds ^{213}Po
See also ^{213}Bi α Decay

Radiation Type	Energy (keV)	Intensity (%)	Δ(g-rad/μCi-h)
Auger-L	8.33	2.4 3	0.0004
Auger-K	59.7	0.13 7	0.0002
ce-K- 1	199.75 10	0.34 6	0.0014
ce-K- 2	347.315 21	4.1 4	0.0302
ce-L- 2	423.481 23	0.72 7	0.0065
ce-MNO- 2	436.271 21	0.226 21	0.0021
β⁻ 1 max	320 10		
avg	90 3	1.06 10	0.0020
β⁻ 2 max	980 10		
avg	319 4	32 3	0.217
β⁻ 3 max	1127 10		
avg	376 4	0.70 19	0.0056
β⁻ 4 max	1420 10		
avg	491 4	64 3	0.669
total β⁻			
avg	430 5	98 5	0.894
X-ray L	11	1.83 23	0.0004
X-ray Kα₂	76.862 5	1.25 12	0.0020
X-ray Kα₁	79.290 5	2.10 19	0.0035
X-ray Kβ	89.8	0.94 9	0.0018
γ 1	292.86 10	0.74 13	0.0046
γ 2	440.420 20	28.0 25	0.262
γ 3	659.81 10	0.148 19	0.0021
γ 4	807.36 4	0.44 4	0.0076
γ 5	1100.14 6	0.48 5	0.0112

• ^{213}Po α Decay (4.2E−6 s 8) I(min) = 0.10%
Feeds ^{209}Pb

Radiation Type	Energy (keV)	Intensity (%)	Δ(g-rad/μCi-h)
α 1	8377 5	99.996 1	17.84

* • ^{214}Pb β^- Decay (26.8 m) I(min) = 0.10%
Feeds ^{214}Bi

Radiation Type	Energy (keV)	Intensity (%)	Δ(g-rad/μCi-h)
Auger-L	8.15	18.6 15	0.0032
ce-L- 1	36.838 14	10.7 6	0.0084
ce-M- 1	49.227 14	2.51 13	0.0026
ce-NOP- 1	52.288 14	0.84 5	0.0009
Auger-K	58.2	0.7 4	0.0008
ce-K- 5	151.455 8	5.29 16	0.0171
ce-K- 6	168.26 6	0.19 14	0.0007
ce-K- 8	204.687 8	7.5 4	0.0326
ce-L- 5	225.593 8	0.92 3	0.0044
ce-MNO- 5	237.982 8	0.290 9	0.0015
ce-K- 12	261.395 8	9.1 6	0.0506
ce-L- 8	278.825 8	1.34 5	0.0079
ce-M- 8	291.214 8	0.316 11	0.0020
ce-NOP- 8	294.275 8	0.105 4	0.0007
ce-L- 12	335.533 8	1.60 7	0.0114
ce-M- 12	347.922 8	0.376 13	0.0028
ce-NOP-12	350.983 8	0.125 5	0.0009
β⁻ 1 max	185 12		
avg	50 4	2.55 8	0.0027
β⁻ 2 max	490 12		
avg	145 4	0.83 6	0.0025

(Continued)

^{214}Pb β^- Decay (26.8 m) (Continued)

Radiation Type	Energy (keV)	Intensity (%)	Δ(g-rad/ µCi-h)
β- 3 max	672 12		
avg	207 5	48.0 14	0.212
β- 4 max	729 12		
avg	227 5	42.5 12	0.205
β- 5 max	1024 12		
avg	337 5	6.3 20	0.0452
total β-			
avg	219 6	100 3	0.468
X-ray L	10.8	13.5 14	0.0031
γ 1	53.226 14	1.11 6	0.0013
X-ray Kα2	74.8148 10	6.21 23	0.0099
X-ray Kα1	77.1079 10	10.5 4	0.0172
X-ray Kβ	87.3	4.67 18	0.0087
γ 5	241.981 8	7.49 21	0.0386
γ 6	258.79 6	0.553 25	0.0030
γ 7	274.53 5	0.33 5	0.0019
γ 8	295.213 8	19.2 6	0.121
γ 12	351.921 8	37.2 11	0.279
γ 13	462.10 20	0.17 3	0.0017
γ 14	480.42 8	0.340 20	0.0035
γ 15	487.08 8	0.441 18	0.0046
γ 17	533.69 8	0.190 15	0.0022
γ 20	580.15 4	0.365 18	0.0045
γ 21	785.910 20	1.10 4	0.0183
γ 22	839.025 15	0.59 3	0.0105

9 weak γ's omitted:
Eγ(avg)= 280.7; ΣIγ= 0.33%

● ^{214}Bi β^- Decay (19.9 m 4) I (min) = 0.10%
%β^- Decay = 99.979 1
Feeds ^{214}Po
%α Decay = 0.021 1

Radiation Type	Energy (keV)	Intensity (%)	Δ(g-rad/ µCi-h)
Auger-L	8.33	0.69 6	0.0001
ce-K- 30	516.207 8	0.69 3	0.0076
ce-L- 30	592.373 13	0.195 8	0.0025
ce-K- 78	1027.182 11	0.192 12	0.0042
ce-K- 98	1322.695 4	0.385 17	0.0109
β- 1 max	541 12		
avg	162 4	0.41 3	0.0014
β- 2 max	551 12		
avg	165 4	0.211 15	0.0007
β- 3 max	575 12		
avg	173 5	0.118 11	0.0004
β- 4 max	762 12		
avg	239 5	0.11 3	0.0006
β- 5 max	764 12		
avg	240 5	0.205 21	0.0010
β- 6 max	788 12		
avg	248 5	1.07 5	0.0057
β- 7 max	822 12		
avg	261 5	2.81 13	0.0156
β- 8 max	977 12		
avg	318 5	0.56 4	0.0038
β- 9 max	1003 12		
avg	328 5	0.14 5	0.0010
β-10 max	1061 12		
avg	350 5	0.336 22	0.0025
β-11 max	1066 12		
avg	352 5	5.61 17	0.0421
β-12 max	1077 12		
avg	357 5	0.89 4	0.0068
β-13 max	1122 12		
avg	374 5	0.43 6	0.0034
β-14 max	1151 12		
avg	385 5	4.43 15	0.0363
β-15 max	1181 12		
avg	397 5	0.144 9	0.0012
β-16 max	1253 12		
avg	425 5	2.50 8	0.0226
β-17 max	1259 12		
avg	427 5	1.50 6	0.0136
β-18 max	1275 12		
avg	434 5	1.19 5	0.0110
β-19 max	1380 12		
avg	475 5	1.59 7	0.0161
β-20 max	1423 12		
avg	492 5	8.34 23	0.0874
β-21 max	1505 12		
avg	525 5	17.7 5	0.198
β-22 max	1527 12		
avg	534 5	0.256 18	0.0029
β-23 max	1540 12		
avg	539 5	17.9 5	0.206
β-24 max	1609 12		
avg	567 5	0.88 12	0.0106
β-25 max	1727 12		
avg	615 5	3.38 12	0.0443
β-26 max	1855 12		
avg	668 5	1.01 6	0.0144
β-27 max	1892 12		
avg	684 5	7.86 24	0.115
β-28 max	1995 12		
avg	726 5	0.22 6	0.0034
β-29 max	2661 12		
avg	1007 6	0.6 3	0.0129
β-30 max	3270 12		
avg	1269 6	17.2 22	0.465
total β-			
avg	632 6	100.0 24	1.35

18 weak β's omitted:
Eβ(avg)= 158.6; ΣIβ= 0.36%

Radiation Type	Energy (keV)	Intensity (%)	Δ(g-rad/ µCi-h)
X-ray L	11	0.52 6	0.0001
X-ray Kα2	76.862 5	0.360 13	0.0006
X-ray Kα1	79.290 5	0.603 20	0.0010
X-ray Kβ	89.8	0.271 10	0.0005
γ 1	273.7 4	0.18 3	0.0010
γ 11	387.0 3	0.37 6	0.0030
γ 12	389.1 3	0.41 5	0.0034
γ 15	405.74 3	0.168 11	0.0014
γ 16	426.5 5	0.11 3	0.0010
γ 18	454.77 12	0.320 16	0.0031
γ 19	469.69 12	0.133 9	0.0013
γ 20	474.38 10	0.118 13	0.0012
γ 30	609.312 7	46.3 12	0.601
γ 39	665.453 22	1.57 7	0.0222
γ 44	703.11 4	0.474 23	0.0071
γ 46	719.86 3	0.405 23	0.0062
γ 51	752.84 3	0.133 11	0.0021
γ 52	768.356 10	5.04 15	0.0825
γ 53	786.1 4	0.32 10	0.0053
γ 55	806.174 18	1.23 5	0.0212
γ 57	821.18 3	0.151 17	0.0026
γ 61	904.25 25	0.106 14	0.0020
γ 63	934.061 12	3.21 10	0.0638
γ 65	964.08 3	0.385 22	0.0079
γ 73	1051.96 3	0.317 16	0.0071
γ 75	1069.96 8	0.286 21	0.0065
γ 78	1120.287 10	15.1 5	0.361
γ 80	1133.66 3	0.256 18	0.0062
γ 81	1155.190 20	1.70 7	0.0418
γ 83	1207.68 3	0.462 22	0.0119

(Continued)

REPORT OF

IN VIVO COUNTING

FOR

NUCLEAR METALS, INC.

2229 MAIN STREET

CONCORD, MASS. 01742

WORK PERFORMED ON

JULY 18 THROUGH JULY 22, 1982

BY

HELGESON SCIENTIFIC SERVICES, INC.
5587 SUNOL BOULEVARD
PLEASANTON, CALIFORNIA 94566

AUTHORIZATION:

PURCHASE ORDER NO. NM 36674

REPORT DATED:

OCTOBER 5, 1983

PREPARED UNDER THE SUPERVISION OF
GEO. LEWIS HELGESON,
CERTIFIED HEALTH PHYSICIST

ATTESTED BY ----- Jeffrey S. Guehring -----

JEFFREY S. GUEHRING
Corp. Health Physicist

I. Equipment

A. Mobile in vivo counting systems for mixed fission, activation, and corrosion products (mfacp), radium and natural thorium.

The detectors used for measuring in vivo depositions of mfacp, radium and thorium are 8-inches in diameter by 4-inches thick and are made from thallium activated sodium iodide, NaI(Tl). some of these detectors use 3 each three-inch diameter photomultiplier tubes for each crystal, others use a single five-inch diameter photo tube. The resolution of the detectors is 8.5% or better for cesium-137 when measured in an essentially scatter-free environment. The output signals from the detector are usually fed to a 256 channel plulse-height analyzer, although in some cases a 128 channel analyzer is used. Output from the analyzer may be obtained in several forms. It may be punched in digital format on paper tape by a high speed paper tape punch, it may be typed and punched by the high speed punch and an IBM computer typewriter, or on a Teletype or it may be recorded on a mass storage device, such as a floppy disk or magnetic tape. It may be displayed in analog format on an oscilloscope, or it may be graphed in analog format on an X-Y recorder.

The shielding for mfacp counting is the standard Helgeson Nuclear Services, Inc. "Do-It-Yourself Whole Body Counter" (tm). The detector is surrounded by 4-inches of lead and the subject lies in a "bathtub" of lead which is 2-inches thick. This and all the electronics plus necessary accessories such as music, lighting, carpeting, etc. are contained in air-conditioned Mobile Scientific Laboratories. Unit No. 3 is 40 feet long by 8-feet wide and Unit No. 4 is 30-feet long by 8-feet wide.

B. Mobile in vivo lung counting system for natural uranium, uranium-235, americium-241, plutonium-238,9, and lead-210

The detectors used for measuring lung depositions of these materials are a pair of 5-inch diameter "phoswich" detectors. Each detector consists of a front entrance window made of 0.010-inch thick beryllium metal, a NaI(Tl) crystal which is 0.5-inches thick to which is optically coupled a 1.5-inch thick cesium iodide (sodium activated) crystal. A single 5-inch diameter eleven dynode photomultiplier views the light pulses from both crystals. The signals from a pair of these detectors are fed in parallel to a low-noise preamplifier and then to a pluse shape discrimination net-work which separates pure NaI(Tl) signals from all other signals. A measured reduction of a factor of 4 in Compton Scattered

Background has been obtained in the uranium-235 photopeak region through the use of this system.

The same analyzers and output devices described above for mfacp counting are available for the low energy counting. The shielding for this work is a totally enclosed shield with the equivalent of approximately 3-inches of virgin lead. This equipment is housed in Unit No. 3, which is a 40-foot long semi-trailer.

C. "Do-It-Yourself Whole Body Counters" (tm) for mfacp

The "Do-It-Yourself Whole Body Counter" (tm) is built quite similarly to the standard Helgeson Nuclear Services, Inc. Shadow Shield Whole Body Counter, i.e., it is built on the principle of shadow shielding. The primary difference lies in the fact that the "Do-It-Yourself" detector moves over the subject, while in the standard shadow shield the subject moves beneath a stationary detector. Outwardly, the detector housings of either shield look quite similar. The bed of the "Do-It-Yourself Whole Body Counter" (tm) looks like a stainless steel bathtub which has two inches of lead in the sides and on the bottom. Four inches of lead are used around the detector.

The detector consists of an 8-inch diameter by 4-inch thick NaI(Tl) crystal and, in most systems, a single 5-inch diameter photomultiplier tube. The electronics are very similar in function but are different in construction. A mini-computer is used both as a logic control device as well as a multi-channel pulse height analyzer and multi-scaler. The computer is programmed to ask the subject for his name, social security number, and other data for identification or physical characteristics. It also gives him instructions of what actions he should take to complete the count and transmit the data to the home office at the end of his count. The data transmission is accomplished by standard telephone lines between the remote site and the home office of Helgeson Nuclear Services, Inc. in Pleasanton, California.

D. Home office equipment

A number of different computing systems are used in the home office. The main systems are Digital Equipment Corporation PDP-8 Series computers with up to 32K of core, disk storage in excess of 3.2 million words, and essentially unlimited magnetic tape storage. Input may be obtained from paper tape, magnetic tape, hard disk, floppy disk, telephone input via a separate message handling computer or by manual input from the various terminals which are part of this system. Output may be obtained in the form of paper tape, magnetic tape, disk, oscilloscope, incremental plotter, X-Y plotter, high speed line printer, or hard and soft copy data terminals.

Data being received over the telephone lines from the "Do-It-Yourself" counters are formatted by a separate message handling computer which may be connected by direct link to the main computer system or whose output may be obtained in paper tape, magnetic tape, or disk format.

II. Calibration

A. Calibration for energy versus channel, "KeV/channel"

The detector and analyzer are calibrated daily for channel versus energy using the technique of Heath described in IDO-16880. For mixed fission, activation, and corrosion products, the energy calibration is determined for each count since a small americium-241 source is attached to the side of the detector. Thus, by using the 59.6-KeV X-ray from americium-241 at the low energy end of the scale and either natural potassium from the subject (or detector) with an energy of 1460-KeV at the high end of the scale, or another known photopeak, such as those from cobalt-60, one has two known energies which may be used as references for a gain and zero shift of the data. This assures that the energy-to-pulse height calibration matches that given by Heath as documented in IDO-16680. Typical calibration results were within an average of 0.5 channels over the energy range of 0.06- to 2.6-MeV.

For uranium-235 counting the energy calibration was set using the 60-KeV photopeak from americium and the 186-KeV photopeak from uranium-235, while for americium-241, plutonium-238, plutonium-239, and lead-210 the gain is set using the 17- and 60-KeV photopeaks of americium-241 as the calibration standard.

B. Calibrations for determining calibration and scatter factors, "counts per minute per nanocurie, etc."

For counting over the entire body the system was calibrated for sensitivity to various radioisotopes by placing up to 240 small uniform activity sources in sugar phantoms which ranged in weights from 27 pounds to 270 pounds. The sources were uniformly distributed in the phantom since it has been shown by previous work that this distribution provides results which adequately reflect the results obtained with non-uniform distribution, such as might be found with insoluble particulates deposited in the lung. The calibration factors vary with body weight as do the Compton Scatter Factors. In most cases these calibration factors may be represented as the sum of two exponential components. Appendix II lists pertinent calibration data. All sources were verified as to their strength by independent laboratories who can reference their sources to the National Bureau of Standards.

Calibrations for uranium-235, americium-241, plutonium-238, plutonium-239, thorium, and uranium-233 (with uranium-232 contamination) have been made by distributing many sources of known activities in a uniform manner in a masonite phantom lung of varying thicknesses. The uranium-235 calibrations have also been checked by counting the lung area of the remab phantom used by the Y-12 Plant, Union Carbide Corporation, Oak Ridge, Tennessee. These results agree well with the masonite calibration results. If these types of measurements were performed as a part of this report, Appendix II contains the appropriate calibration data.

Americium-241, plutonium-238, plutonium-239, thorium, and uranium-233 calibrations were performed in the same manner as uranium-235 except that no cross-check has been done with the Y-12 phantom. Plutonium-238, and plutonium-239 calibration factors which have been provided by P. N. Dean, Los Alamos Scientific Laboratories, are routinely used.

III. Counting techniques

A. Mixed fission, activation and corrosion products and radium-226

The counting techniques for the mobile counters are described in the following paragraph. The counting techniques for the "Do-It-Yourself Whole Body Counter" vary only slightly from that described below, the principal difference being that the detector moves over the subject as opposed to the subject moving under the detector as in the mobile systems. Another minor difference lies in the fact that the detector moves the same distance for every subject regardless of the height of the subject.

The shadow shield whole body counter built by Helgeson Nuclear Services, Inc. follows closely the basic principles of its originators, H.E. Palmer and W.C. Roesch. They have shown that if a subject is placed with his head 4 inches to one side of the detector and travels so that his feet are 4 inches on the other side of the detector at the end of the count, 95 percent of all the counting information which could have been obtained by traveling an infinite distance on either side of the detector will have been obtained. Thus, tapes calibrated in feet and inches have been placed on the floor of the counter with the zero inch mark located 8 inches from the center line of the crystal. To position a person properly one need merely place the bottom of his feet at a distance which corresponds to his height. The bed speed is then adjusted such that the total travel time for a given individual is in the range of 5- to 60-minutes, depending on the statistical precision desired and on the degree of difficulty in measuring certain radionuclides. For example, a radium-226 measurement takes at least 40-minutes. In this manner the various critical organs are scanned by the detector for the same percentage of the total counting time as were the corresponding organs in the phantom. Most counts for mfacp are for 6- to 8-minutes.

All persons were counted in the supine position unless otherwise noted. The head was allowed to rest directly on the bed of the counter rather than being elevated on a pillow.

In only a few facilities are people counted while wearing all of their street clothing. This practice is generally discouraged. At other facilities, however, where the probability of personal clothing contamination is greater, people will be counted in paper lab coats only. If women are to be counted in other than their street clothing, a second woman attendant would be requested. All disrobing would be done in privacy.

All persons were to have showered after leaving a potentially contaminated area. Helgeson Nuclear Services, Inc. assumes no responsibility for ensuring that subjects are free of external contamination.

B. Uranium (enriched, natural, depleted), plutonium-238 and americium-241

Uranium-235, plutonium-238, 239, and americium-241 are counted in the totally shielded counter contained in Unit 3. The detectors are placed directly in contact with the chest of the subject such that the detectors will "see" major portions of the lung. For uranium-235 they are positioned such that the detector is centrally located between the bottom of the clavicle (collar bone) and the center line of the nipples and are at the outer edges of the sternum. This usually places the top edge of the detector about one inch below the lower edge of the clavicle. The normal counting time for uranium-235 is 20-minutes. Natural and depleted uranium may be measured by the same method as is used for uranium-235, i.e., the 186-KeV photopeak is used for calculating the lung burden. If information is desired on the daughter products protoactinium-234 and thorium-234, the 63- and 93-KeV photopeaks are used. In certain circumstances, such as a high environmental background count is also made as discussed in the next paragraph.

For plutonium and americium counting the detectors are positioned such that the top edge of the detector is tangent to the bottom of the clavicle and the inner edges of the detector are tangent to the outer edges of the sternum. The counting time for americium-241 is 40-minutes. The counting time for plutonium is 40-minutes on the chest, with this data being recorded, followed by a background of 40-minutes with the detectors placed on the thighs. Additional time is required for plutonium-238, 239 for measurements using an echoencephaeloscope to determine the chest wall thickness. The length of time for these measurements varies between 10-to 20-minutes. Other measurements required for plutonium-238, 239, americium-241 and uranium-235 are the height, weight, and chest circumference.

Effective chest wall thickness is determined by measurement of the chest wall thickness in at least 12 different locations using an echoencephalscope and is calculated by the method of Rundo et al (Health Physics, Vol. 17, PP 155-157, 1969) and by Dean's Empirical Formula.

C. Thorium

Thorium is counted by positioning the chest of the subject beneath the 8-inch by 4-inch detector with a bed-to-detector distance of 10.5-inches or 12.5 inches. The subject is counted for 40-minutes without changing the counting geometry of the chest and the detector.

IV. Sensitivity

A. Mixed Fission, activation, and corrosion products and radium-226

The sensitivity of the system is a function of the background radiation levels, the size and efficiency of the detector, the detector-subject geometry, and the counting time. The background in the mobile systems is carefully monitored at various intervals during the counting period. The detector-subject relationship is normally constant at 12.5-inches between the face of the crystal and the top of the bed, although this may be changed to 10.5-inches or 14.5-inches as the need warrants. Since the presence of radioisotopes other than fallout cesium-137 or naturally occurring potassium will cause a rise in the apparent "background" due to Compton Scatter, the actual sensitivity varies somewhat.

Appendix III presents a Table of Minimum

Sensitivities. If a radionuclide listed in Appendix III is not listed in Appendix I, then it is not present in an amount equal to or greater than that listed in the column labeled "Min. Sen., NcI".

The background of the "Do-It-Yourself Whole Body Counter" is continuously being determined when a subject count is not being made. Every 16-minutes the current background just completed is transferred to a different memory location and a new background is started. This cycle is continuous. If a subject count should be started before the current 16-minute period has been completed, but after 8-minutes has elapsed since the start of the current background, the shorter background will be saved. If less than 8-minutes has elapsed in the current background, the data are aborted and the previous background is used. Thus, one will always have a current and statistically representative background.

B. Other radionuclides

The sensitivities for uranium-235, plutonium-238, 239, americium-241 and thorium are likewise a function of the background, detector size, detector-subject geometry and the counting time. The total chest thickness as well as the chest wall thickness also affect the sensitivity for low energy radionuclides. See the calibration data in Appendix II for the variation of the calibration factors as a function of these parameters. Typical numerical values for minimum sensitivities are 30 - 60 micrograms of U-235, 1 to 3 milligrams of natural or depleted uranium, 4 - 50 nanocuries of Pu-238 and 239 (highly dependent on chest wall thickness), 0.05 - 0.1 nanocuries of Am-241 and 6 - 8 milligrams of natural thorium.

V. Statistical evaluations

A. General discussion

Statistical analyses of the data use standard techniques. Random counts observed from nuclear disintegrations have been shown to follow the Poisson Distribution. However, for the number of counts observed over the typical counting times, the Poisson Distribution may be evaluated with a high degree of confidence by using the characteristics of the normal (Gaussian) distribution. Thus, the average gross counting rate for potassium, for example, is typically found by dividing the total of the counts observed in channels 132 through 155, inclusive, by the counting time in minutes, or,

$$G = (\text{Sum of Channels } 132 - 155) / T.$$

The variance of the counting rate is equal to the long term expected counting rate divided by the counting time, or,

VAR(G) = G/T

Net counting rates are found from the relationship

N = G - B,

Where G = Gross counting rate obtained in T minutes and
B = Background counting rate obtained in T(B) minutes.

The variance of the net counting rate is found from

VAR(N) = VAR(G) + VAR(B),

While the standard deviation of the net counting rate is the square root of the variance of N.

The actual amount of activity, A, found in the subject is therefore obtained by dividing the net counting rate, after correcting for Compton Scatter where necessary, by the calibration factor, F.

A = N/F

The variance of A is found from the relationship

VAR(A) / (A*A) = VAR(N) / (N*N) + VAR(F) / (F*F)

The asterisk, (*) is used here to signify multiplication while the slash, (/), signifies division.]

In most cases the variance of the calibration factor, VAR(F), is small compared to the variance of the subject data, VAR(G), and is assumed to be negligible. The statistical error due to Compton Scatter from isotopes which are actually present is included in the calculation of the VAR(A).

B. Evaluation of data For natural or depleted uranium, U-235, Pu-238,9, Am-241

Prior to any data reduction the original data for these radionuclides are plotted for inspection by the analyst. The data may be smoothed according to the methods of Savitzky and Golay (Analytical Chemistry, 36, #8, July '64, PP 1627 - 1639) for the purpose of minimizing random statistical variations but preserving photopeak structure. This helps significantly in further evaluation of the data.

Most of the data reduction for U-235, natural uranium, and depleted uranium utilizes the Compton Continuum Subtraction Technique. In some circumstances a non-linear curve-fitting routine may be used. The techniques used for plutonium analyses may also be employed. See the next paragraph.

Data reduction from Pu-238, Pu-239, and Am-241 analyses is much more involved than that for uranium analyses. The background from the thigh count is assumed to be representative of the background which would have been obtained over the chest if one could have been assured that no plutonium or americium had been present in the chest. This is a reasonable assumption for most situations. Several other radionuclides have been seen in the lungs of several individuals, principally cobalt-60. These require special techniques, the description of which is beyond the scope of this document. The lung and thigh data are smoothed by the method of Savitzky and Golay and are displayed on he oscilloscope screen in either a linear or logarithmic presentation. The analyst may subtract fractions of the thigh data and display the net counting rate. Normally, 100-percent of the thigh data are subtracted from the lung data. In those instances where the net counting rate is entirely negative after subtracting 100 percent of the thigh data, small amounts of the data are added back to the net counts to obtain a graph in which approximately half of the net counts are positive and half are negative in the background regions adjacent to the photopeaks of interest. These data are then used in the Compton Continuum Subtraction program to obtain the actual net counting rate under the photopeaks of interest.

The chest wall thickness is determined by three methods as described in Section III. At least 12 chest wall thickness measurements are made using an echoenceph-aloscope. Since the transmission of low energy x-rays is an exponential function of the chest wall thickness, a calculation is made to determine the average transmis-sion. The average chest wall thickness is back-calcul-ated from this information. Thus, the 2 sigma standard deviation is skewed due to the use of the log-normal distribution. A linear absorption coefficient of 1.15 per centimeter is used for human tissue at 17-KeV. The chest wall thickness is also calculated by the method from Dean of Los Alamos:

THICKNESS, CM = 0.007 + 5.12* (WEIGHT, KG) / (HEIGHT, CM)

The wall thickness is also calculated by the method of Rundo:

Thickness, cm = 15.3 * (Weight, kg) / (Height, cm) - 0.01 * Circumference, cm - 3.55

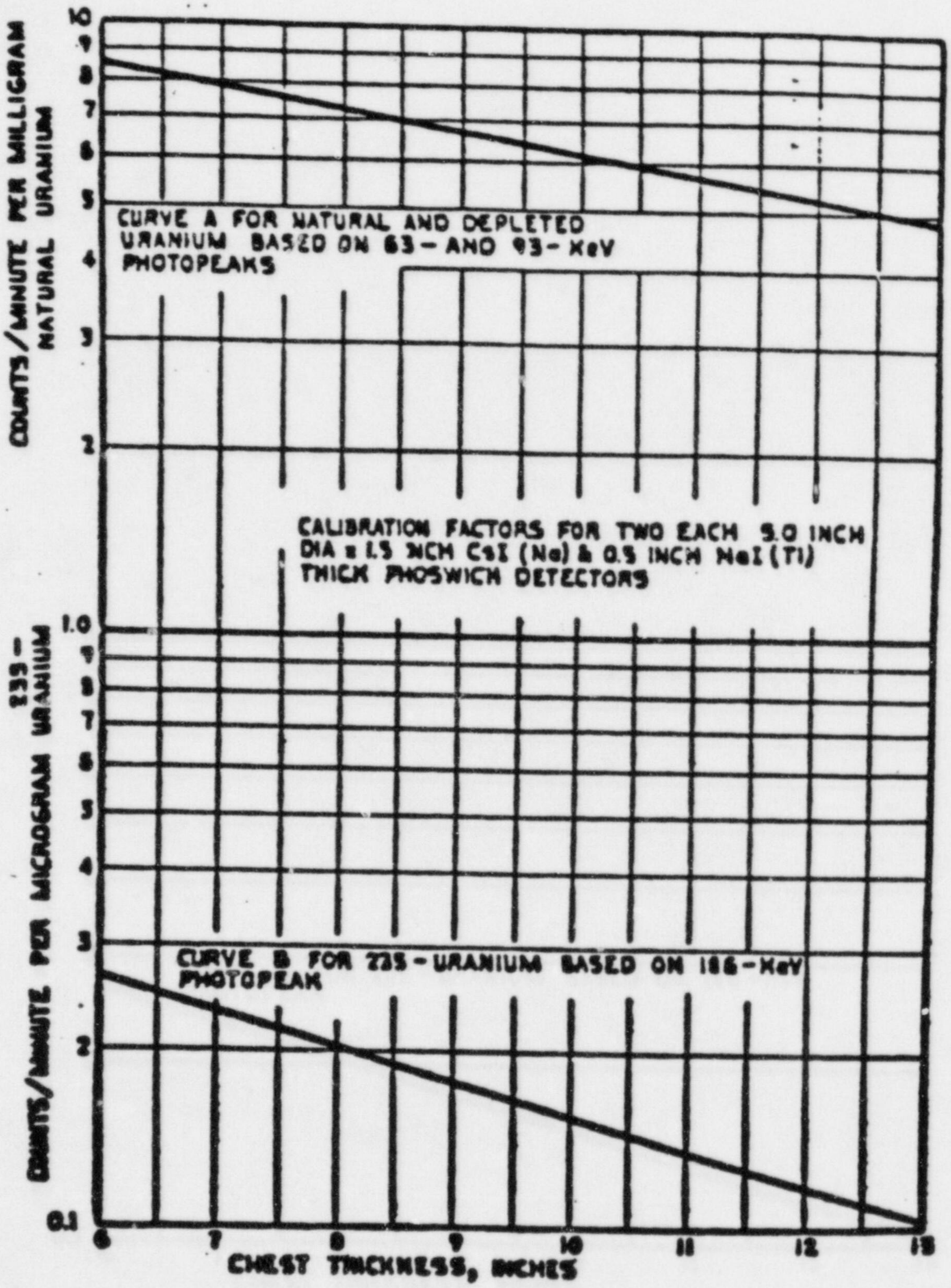
The chest wall thickness as determined by the echoencephaeloscope is normally used in the calculation of the calibration factors unless it is significantly different from those obtained by the methods of Dean and Rundo. The calibration factors for Pu-239 and Am-241 are identically the same values as used at Los Alamos and are:

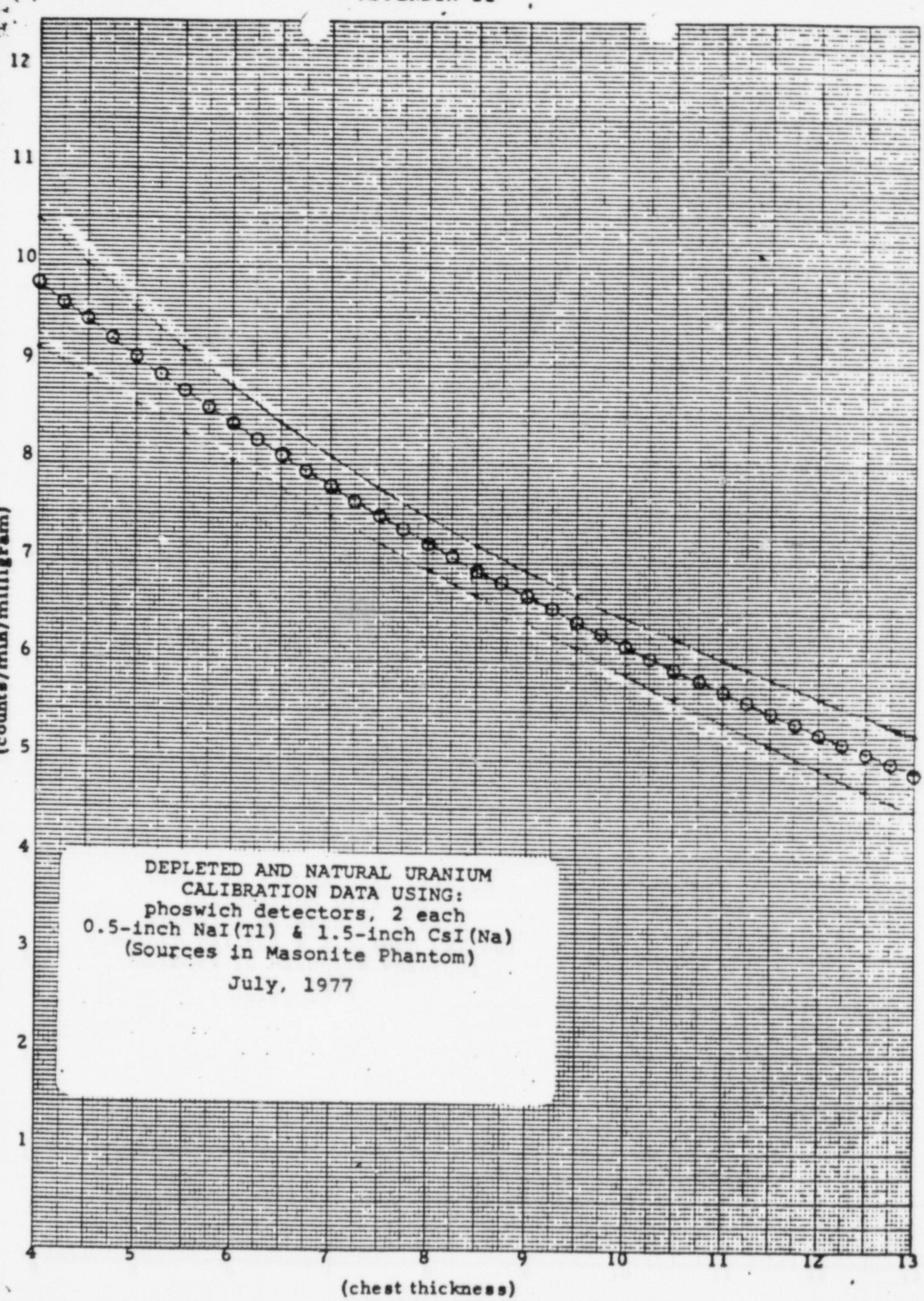
Calibration factor, Pu-239 = 39.48897 *exp(0.836646 * ct)

Ratio, Am-241 scatter in Pu-239 channels to Am-241 counts =

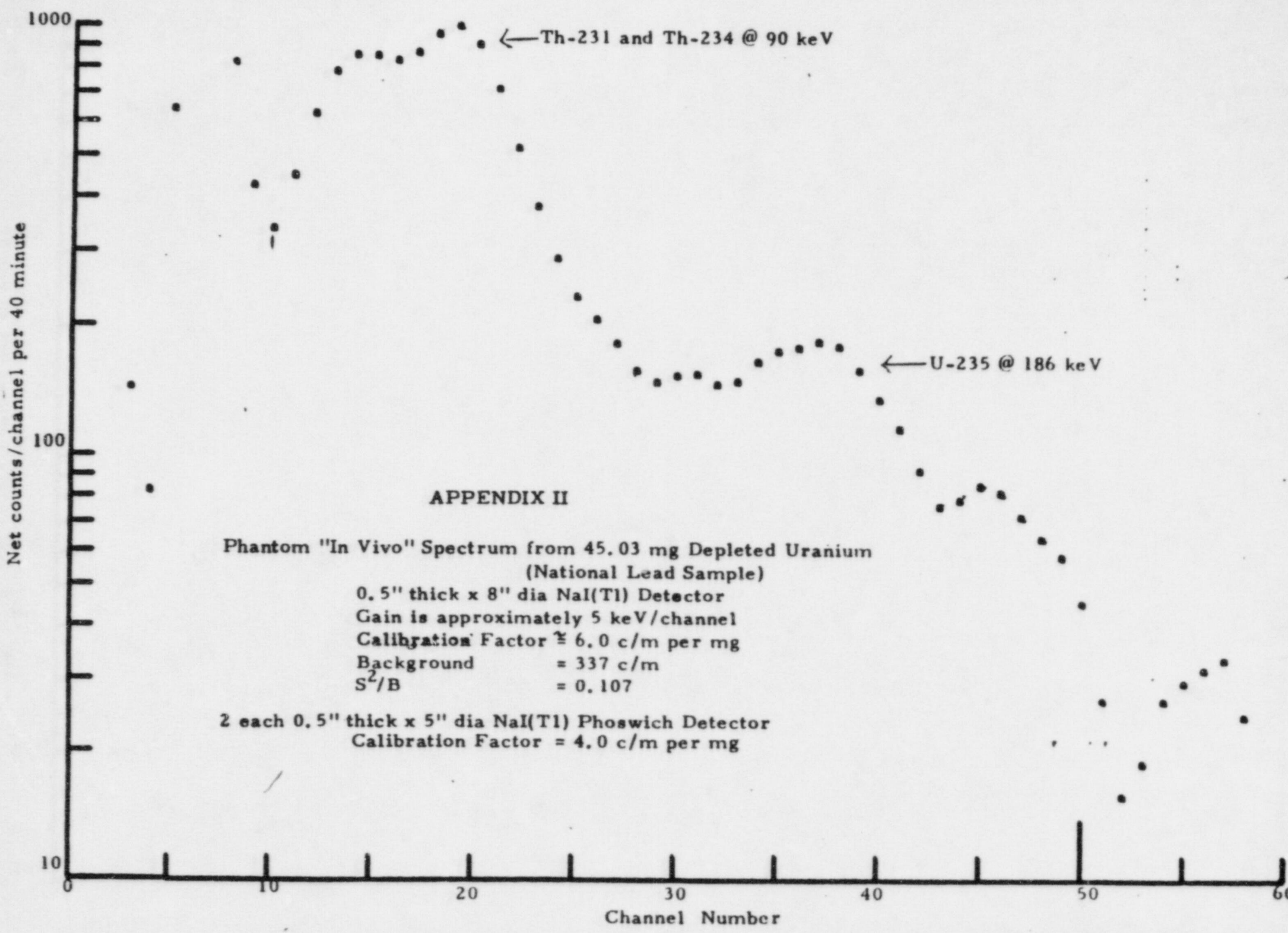
0.2 * exp(-0.039*ct) + 0.8 * exp(-1.09*ct)

Calibration factor, Am-241 = 1.396 * exp(0.143655 * ct)
Where ct = chest thickness, centimeters.

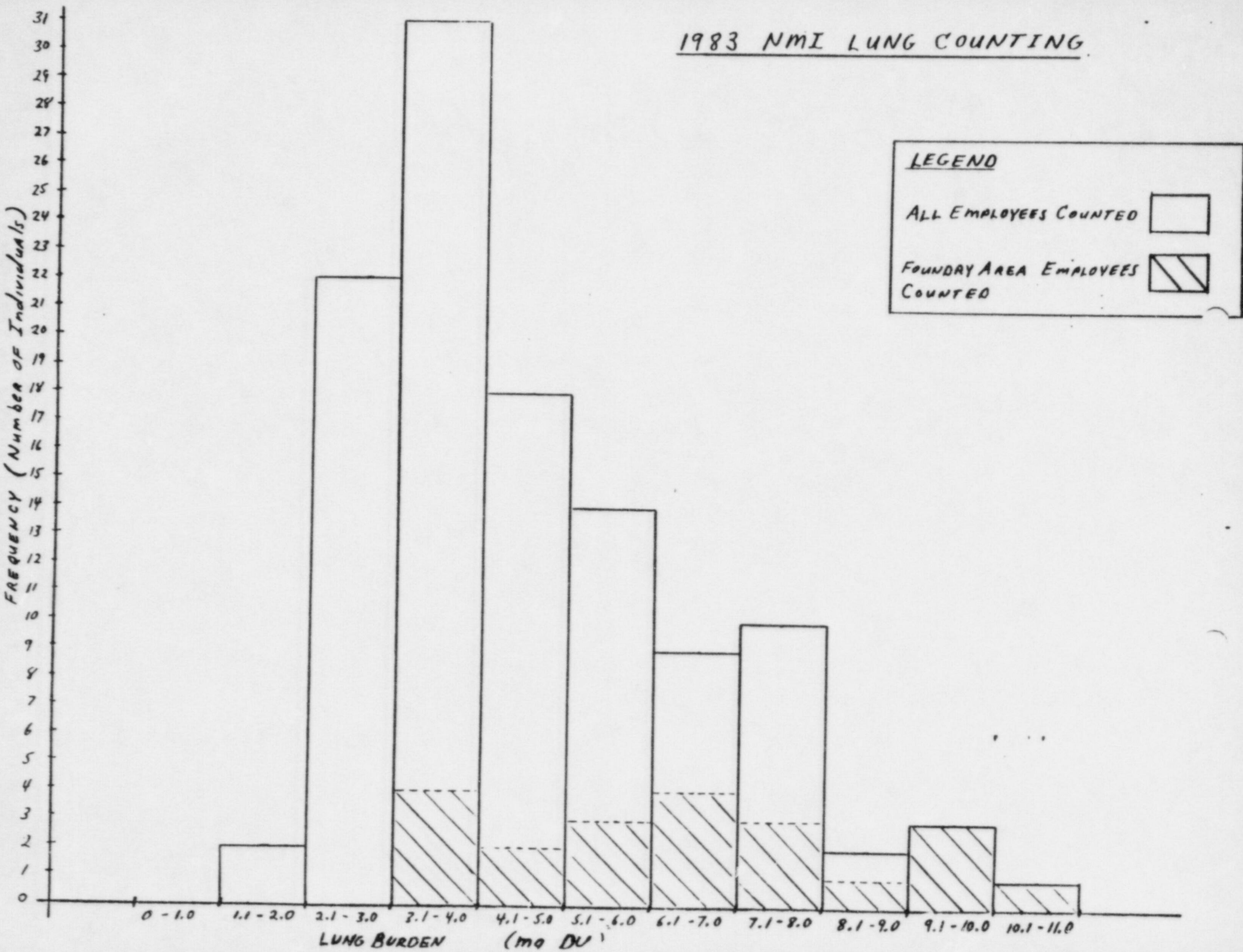

COUNTS/MINUTE PER MILLIGRAM NATURAL URANIUM
CURVE A FOR NATURAL AND DEPLETED URANIUM BASED ON 63- AND 93-KeV PHOTOPEAKS
CALIBRATION FACTORS FOR TWO EACH 5.0 INCH DIA x 1.5 INCH CsI (Na) & 0.5 INCH NaI (Tl) THICK PHOSWICH DETECTORS
COUNTS/MINUTE PER MICROGRAM 235-URANIUM
CURVE B FOR 235-URANIUM BASED ON 186-KeV PHOTOPEAK
CHEST THICKNESS, INCHES
10
9
8
7
6
5
4
3
2
1.0
9
8
7
6
5
4
3
2
0.1
6
7
8
9
10
11
12
13



DEPLETED AND NATURAL URANIUM
CALIBRATION DATA USING:
phoswich detectors, 2 each
0.5-inch NaI(Tl) & 1.5-inch CsI(Na)
(Sources in Masonite Phantom)
July, 1977



1000
100
10
Net counts/channel per 40 minute
←Th-231 and Th-234 @ 90 keV
←U-235 @ 186 keV
APPENDIX II
Phantom "In Vivo" Spectrum from 45.03 mg Depleted Uranium
(National Lead Sample)
0.5" thick x 8" dia NaI(Tl) Detector
Gain is approximately 5 keV/channel
Calibration Factor ≈ 6.0 c/m per mg
Background = 337 c/m
S²/B = 0.107
2 each 0.5" thick x 5" dia NaI(Tl) Phoswich Detector
Calibration Factor = 4.0 c/m per mg
0
10
20
30
40
50
60
Channel Number


1983 NMI LUNG COUNTING
LEGEND
ALL EMPLOYEES COUNTED
FOUNDRY AREA EMPLOYEES COUNTED
FREQUENCY (Number of Individuals)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
0 - 1.0
1.1 - 2.0
2.1 - 3.0
3.1 - 4.0
4.1 - 5.0
5.1 - 6.0
6.1 - 7.0
7.1 - 8.0
8.1 - 9.0
9.1 - 10.0
10.1 - 11.0
LUNG BURDEN (mg DU)

NUCLEAR METALS, INC.

RADIOLOGICAL WORK PERMIT SYSTEM

SPECIFICATION

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

1. BACKGROUND

The Nuclear Regulatory Commission (NRC) requires that all of its licensees maintain Radiation Safety Programs that assure not only that radiation exposure levels are kept below NRC prescribed limits, but also that exposure levels are maintained at levels as low as are reasonably achievable (ALARA), which may be well below prescribed limits. The NMI Radiation Safety Program is designed to satisfy both of these goals. However, achieving the goals in actual practice requires the total commitment of all NMI employees at all organizational levels to the program, and strict adherence to all of the procedures through which the program is implemented.

The NMI Radiation Safety Program is comprised of four program elements.

(1) The Radiological Work Permit Program. Radiation Work Permits (RWPs) identify actual and potential radiation hazards associated with particular operations (like melt and cast) and the precautionary measures (including the use of protective clothing, dosimeters, etc.) that will reduce exposure ALARA. Thus, Radiological Work Permits establish the prerequisite conditions that must be satisfied before operations covered by the Work Permits are allowed to begin. RWPs are prepared by the Health Physics Department.

(2) The Radiation Surveillance Program. The Radiation Surveillance Program is designed to assure that all operations with associated actual or potential radiation hazards are covered by appropriate Radiation Work Permits and that all provisions of the RWPs are being rigorously followed. The Radiation Surveillance Program is carried out by Health Physics Technicians in accordance with procedures developed by the Health Physics professional staff and endorsed by NMI executive management. Health Physics Technicians are authorized by NMI management to stop any operations that fail to comply with the requirements of the governing RWPs.

(3) The Radiation Safety Training Program. In order to achieve ALARA objectives, every NMI employee at every organizational level must fully understand the actual and potential radiation hazards that accompany NMI research, development, and manufacturing operations as well as the precautionary and protective measures that will maintain the hazard levels ALARA. The NMI Radiation Safety Training Program is designed to achieve these objectives.

(4) The Radiation Safety Audit Program. The Radiation Safety Audit Program, executed by the Health Physics Department, is designed to assure: (a) that the other three programs are functioning effectively and that personnel exposure levels do not exceed regulatory limits; and (b) that opportunities for further reduction of exposure levels are pursued in accordance with the NMI/NRC ALARA philosophy.

Details of the Radiological Work Permit Program are covered by this specification.

2. PURPOSE AND SCOPE OF THE RADIOLOGICAL WORK PERMIT PROGRAM

NMI management has historically been, and continues to be, fully committed to the occupational safety and health of all of its employees. The company, therefore, fully supports NRC requirements, including its ALARA philosophy, as a means of protecting the safety and health of its employees. The NRC encourages that its licensees develop and implement Radiation Work Permit Systems as a means of achieving ALARA objectives. The Radiological Work Permit System described by this specification satisfies NMI's traditional concern with the occupational safety and health of its employees as well as maintaining occupational radiation exposures ALARA.

The purpose of a Radiological Work Permit (RWP) is to identify the actual and potential radiation hazards associated with an operation or process involving radioactive materials (including low specific activity radioactive materials like depleted uranium used in NMI manufacturing processes) and to specify the mandatory protective/precautionary measures that must be taken to assure that exposure levels are maintained as low as is reasonably achievable (ALARA) for that operation or process. No person is authorized to undertake that operation or process without first fully complying with the conditions specified by its governing RWP.

In scope, the NMI RWP Program is intended to cover all operations and processes conducted within restricted areas and all personnel (employees, visitors, and contractors) entering, working within, and leaving restricted areas. RWPs are to be prepared for every operation or process undertaken within NMI restricted areas, even those operations/processes for which no special precautionary measures are required. In these latter cases, the RWPs may state that no precautionary measures are necessary. However, RWPs will be issued to assure that 100% of operations within the restricted areas are covered by RWPs.

3. RADIOLOGICAL WORK PERMITS

Radiological Work Permits (RWPs) are authorizations issued to and signed by each person entering into or working within NMI restricted areas. RWPs specify the prerequisite training and the mandatory radiation safety and exposure monitoring requirements that must be observed by the person signing the RWP whenever he or she is undertaking the operation covered by the RWP. Failure to comply with the requirements of the RWP may lead to the suspension or revocation of the RWP without which the person is not authorized to perform the specified work.

The NMI Radiological Work Permit System makes use of two types of RWPs: Standing RWPs and Special RWPs. Standing RWPs cover standard manufacturing, maintenance, and housekeeping operations. They are prepared by members of the Health Physics staff, but actually issued by line supervisors. Standing RWPs are reviewed periodically to assure that they are consistent with the NMI ALARA philosophy but changed only when there is a change in the operation/process they cover or when a reasonable opportunity for reducing exposure levels can be affected.

Special RWPs are prepared and issued by the Health Physics Department to cover special maintenance, repair, spill clean-up, facilities modification, etc., work in restricted areas. Special RWPs are valid only for the period of time specified on the RWP.

3.1 Format and Content of Standing RWPs

The format for Standing RWPs is as shown in the illustrative example (Figure 3-1). Different information contained on the form is identified by numbered circles on the sample; meanings and functions of this information are described in the paragraphs that follow.

(1) The date that the RWP was prepared by a member of the Health Physics staff is included here.

RADIOLOGICAL WORK PERMIT NUCLEAR METALS INC.	EF. CTIVE DATE (1)	NUMBER (2) XXX - YYY
	(3) PAGE OF	(4) REVISION 22

TITLE: BILLET ASSEMBLY (5)

Radiation Protection Procedures: (6)

The individual(s) must have undergone a training program in the fundamentals of radiation protection, exposure control and specified company rules for the particular radiation area in which he/she works. This training will be supplemented by annual retraining.

The following personal equipment shall be worn at all times by individuals conducting the above operation:

a). One "whole-body" film badge worn on the upper chest region. (Right side if right-handed, left side if left-handed.)

b). One NMI picture "whole-body" TLD badge worn adjacent to "whole-body" film badge.

c). Safety glasses.

d). Steel toe "hot" shoes.

e). Company uniforms must be worn.

f). Personal Air Monitors (PAM) when issued.

Special Safety Precautions: (7)

1). Welding shield is to be worn during welding.

2). Welding is to be conducted within the designated area with the plastic curtain in place or inside the weld shop.

3). Smoking, eating or drinking in any restricted area is prohibited.

4). Urine samples to be submitted monthly for urinalysis.

(8) Accepted by:	Certified by:	Issued by:
Name (Individual)	Name (Supervisor)	Name (Health Physics)
Employee No.	Employee No.	Employee No.
Date	Date	Date

(2.) This is a control number that uniquely identifies the RWP. It is divided into two groups of three digits each. The first group (XXX) identifies the NMI department for which the RWP was originally prepared. As examples, 520 would designate the Billet Assembly Department, 541 the Downstairs Machine Shop, etc. Although it may subsequently be applied to another NMI department, the three digit prefix remains the same. The next three digits (YYY) are simply a serial number to differentiate different RWPs issued to the same work area.

(3.) Insofar as possible, it is the intent of the Health Physics Department to confine RWP information to a single sheet of paper. For some complex operations it will be impossible to do so, in which case additional pages may be added. The total number of pages in the RWP will then be identified at the top of the form in field (3.)

(4.) RWPs may be revised from time to time. The revision indicator is entered here. For the initial issue of the RWP, this field will be left blank. However, the first revision will have an "01" entered here; the second "02"; etc.

(5.) The title of the RWP is entered here, which names the operation covered. If a Standard Operating Procedure has also been written for the operation, it will be identified with the RWP title.

The information contained in the body of the RWP is divided into two general groupings: Radiation Protection Procedures and Special Safety Precautions.

(6.) The section "Radiation Protection Procedures" covers personal prerequisites like the training that a mechanic must have had to prepare him for undertaking the operation and the protective clothing and monitoring apparatus that he must wear when performing the operation.

(7.) The section "Special Safety Precautions" specifies requirements that are unique to the operation being performed like the requirement for special shielding, for the periodic submission of urine samples, etc.

(8.) At the bottom of the RWP (or on the reverse side of the page if there is insufficient room on the front) there are provisions for three signatures. The first is the space for the employee's, plus spaces for his or her employee number and the date the RWP is signed. By signing the RWP the employee signifies that he fully understands the requirements and agrees to comply with them. The second space is for the employee's supervisor's signature plus spaces for the date and his employee number. By signing the RWP, the supervisor confirms that the employee signature is valid and that the supervisor assumes responsibility for employee compliance with the provisions of the RWP. The third signature is for the Health Physics staff member that prepared the RWP. By signing the RWP the H.P. staff member certifies the effectiveness of RWP requirements in reducing exposure levels ALARA.

Once the RWP has been signed by all three parties, three copies are made. One is retained in the departmental office; the remaining two are returned to Health Physics where one copy is filed with the RWP master by RWP Number, and the other in the personnel certification/exposure file by employee number. The RWP file will thus provide information on all employees certified under each RWP; the personnel file will identify all of the RWPs for which each employee has been certified.

3.2 Format and Content of Special RWPs

Special RWPs are prepared on request by Health Physics to cover all operations (including contractor work and visitors) in NMI restricted areas not otherwise covered by Standing RWPs. Special RWPs authorize work for a limited period of time only and must be re-issued if the work covered by the RWP is not completed within the period originally specified. Should an operation requiring a Special RWP become a routine occurrence, it will be considered for a Standing RWP classification.

Format of Special RWPs is shown in Figure 3-2. Like Standing RWPs, each Special RWP is given a unique number consisting of the three digit department number followed by a three digit serial number. To avoid confusion with Standing RWPs, Special RWP numbers are prefixed with an "S" for specials issued to NMI units, with a "V" for RWPs issued to visitors and with a "C" for contractor RWPs. Contractor organizations will also be assigned a three digit number (like the NMI department number) to identify the contractor.

Content of the Special RWPs is divided generally into four parts (Figure 3-2). Part (1) contains information describing the operation for which the RWP is being requested. This portion of the RWP is filled in by the requestor who submits the form to Health Physics for action. Normal turn-around time for processing requests for Special RWPs will be five

FIGURE 3-2

NMI

Radiological Work Permit

Health Physics

No. ______

TO BE COMPLETED BY REQUESTOR

(1)

Submittal Date: ________________ Supervisor & Dept.: ________________

Location: ________________ Est. Time: ________________

Description of work: (use separate sheet if necessary) ________________

Personnel performing work:

FOR HEALTH PHYSICS USE ONLY

Monitoring Requirements

(2)

	HP Audit	
___ WB TLD	___ None Required	___ Special Shielding
___ Wrist TLD	___ Start of Job	___ Work Area Release
___ Finger TLD	___ Continuous	___ BZAS

Protective Clothing Requirements

Head	Body	Hands	Feet	Respiratory
___ Disp. Hat	___ Paper Suit	___ Lead Gloves	___ Shoe Covers	___ Full Face Mask
___ Disp. Hood	___ Standard	___ Surg. Gloves	___ Work Shoes	___ 1/2 Face Mask
___ Face Shield	Uniform	___ Leather Gloves	___ Rubbers	___ SCBA
___ Other	___ Other	___ Other	___ Other	___ Other

(3)

Radiation Conditions - Estimated by survey meter #

Location	WB (mrem/hr)	Skin (mrem/hr)	Ext. (mrem/hr)	Wk. Time	Dose (mrem)
					WB
					Skin
					Ext.

Sampling Results

Name	Dose (mrem)	Air Concentration (µCi/l)	Urinalysis (µg/l)	Removable Contamination α (dpm/100cm^2)	β

Comments: ________________

(4)

Authorization - Operational Period: ________________

Pre-job conference required? YES: ________________ NO: ________________

	Name	Date		Name	Date
Workers:			Supervisor		
			HP Tech		
			HP Staff		

HP

HP FORM NO. 91 August 26, 1983

working days; accordingly the requestor must anticipate this turn-around and file the requests sufficiently far in advance of the need date that the work won't be delayed for want of the requisite RWP. Emergency RWPs will, however, be processed immediately on receipt by Health Physics.

Parts (2) and (3) of the Special RWP are completed by Health Physics. Part (2) specifies the mandatory protective clothing and monitoring equipment required of all personnel undertaking the special operation covered by the RWP. Part (3) provides an assessment of the radiological hazards that may be associated with the operation. It also includes space for the recording of exposure information obtained on completion of the operation for each of the people that participated in it.

Part (4) provides space for the requisite signatures to authorize the RWP as well as spaces for the responsible persons that must accept responsibility for compliance with all requirements of the RWP.

Part (4) also specifies the effective period of the RWP by means of the beginning and ending dates included here. If a pre-job conference is required, it will be specified in this part of the form.

Workers' names authorized to participate in the operation are listed in Part (4) of the form. Note that these may not be the same as those listed at the top of the form by the requestor because of cumulative exposure levels, the lack of required training, or other reason. The personnel files noted in Section 5 of this specification will be used to screen personnel for assignment to all Special RWPs.

3.3 NMI Radiological Work Permit Policy

No work will be permitted in restricted areas unless that work is covered by a Standing or Special RWP. This requirement not only applies to NMI employees, but also to all contractors and all visitors. It is the responsibility of cognizant NMI personnel (visitor escorts, for example) to assure that this requirement is fulfilled. Health Physics should be notified if a visitor will need to enter a restricted area. Special RWPs for contractor personnel will be provided by Health Physics on request, as well.

4. RADIOLOGICAL WORK PERMIT PROCEDURES

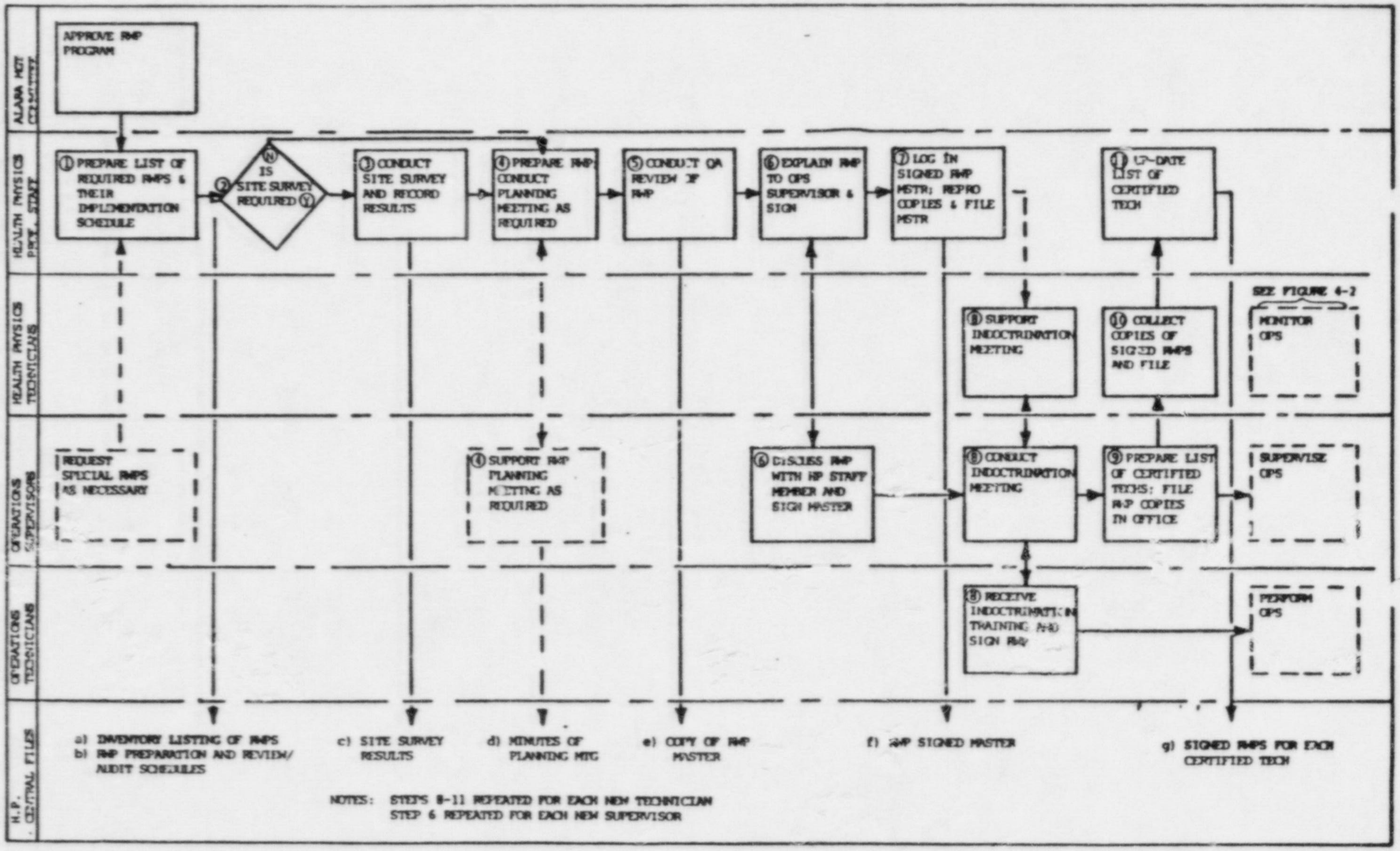
Procedures for implementing the RWP System are divided into two groups: (1) those involved in preparing and issuing RWPs; and (2) those used in monitoring departmental compliance with the requirements of RWPs after issue. These two sets of procedures are shown schematically in Figures 4-1 and 4-2 and described in detail in subsections 4.1 and 4.2 that follow.

4.1 The RWP Formulation Process (Figure 4-1)

Step 1: To assure that the proper degree of coverage is achieved in the RWP Program, it is necessary to identify and list each RWP that will be required. This list is a dynamic list since it will be frequently up-dated as older RWPs become obsolete and the requirements for new RWPs emerge. Step 1 in the RWP formulation process involves developing an initial list of RWPs anticipated to provide the degree of coverage required, and subsequently up-dating the initial list as new requirements are uncovered. Each RWP in the listing will be assigned a priority as well as a schedule of dates when the various actions needed to prepare and issue the RWP are to be completed. In addition, responsibility for the preparation of each RWP on the list will be assigned to a member of the Health Physics Department professional staff. Thereafter, members of the staff will prepare the RWPs assigned to them in accordance with the completion schedule milestone dates assigned to those RWPs. As the work proceeds with the preparation of the RWPs, the listing is updated to reflect the current status of each RWP on the list. Typical milestone dates for each RWP include the following:

- Radiological site survey (if required) completed
- Draft RWP completed
- QA Review of RWP completed
- Supervisor indoctrination completed
- Operations technical indoctrination completed
- RWP issued and effective
- Date RWP is to be reviewed

FIGURE 4-1: RWP SYSTEM
IMPLEMENTATION PROCEDURES



Special and emergency RWPs can be added to the list at any time. These will be assigned suitable priorities to assure that they are prepared and issued on or before the date they are needed.

Step 2: Health Physics personnel can proceed with the preparation of the RWPs assigned to them in accordance with the schedule contained on the RWP Master listing. The first step in doing so will be to determine if a radiological survey of the site and/or operation is required. In determining the need for a survey, the Health Physics Staff member may refer to the file for review of prior survey data and to the SOP for the operation. If it is determined that a survey should be accomplished, the Health Physics Staff member will proceed to Step 3; otherwise, he may begin drafting the RWP, proceeding directly with Step 4. (Note: In preparing the initial set of RWPs required to set up the RWP program, site surveys will most likely be deferred, but where they are thought to be needed, they will be scheduled for accomplishment at a later date. The master RWP listing should be annotated to flag the need for later site/operations radiological surveys.)

Step 3: If a site survey is required, it will be accomplished as Step 3 in the RWP formulation process. Note that in the case of an incident requiring a Special RWP (such as a mispour in the foundry) a site survey will be mandatory. Site surveys of this nature may also be accompanied or followed by a planning meeting to determine the type of restorative/repair action needed. Results of the site survey (and planning meeting if required) are to be documented, referenced in the RWP that is prepared during Step 4, and filed with the RWP in the HP Master RWP File.

Step 4: The RWP itself is prepared during this step using the forms described in parts 3.1 and 3.2 of this specification.

Step 5: RWP formulation procedures require that each RWP be subjected to an independent review by a member of the Health Physics staff to assure completeness, accuracy, etc., prior to its issue to operations. This review is accomplished during Step 5. The reviewer is required to initial the RWP to acknowledge responsibility for RWP quality.

Steps 6 and 7: Step 6 consists of a meeting between the HP Staff member that prepared the RWP and the operations supervisor that must comply with its requirements. Both must sign the face page of the RWP. By signing the RWP, the Health Physics Staff member assumes responsibility for the effectiveness of the provisions of the RWP in reducing radiation hazards ALARA; the operations supervisor assumes personal responsibility for his own compliance with the requirements of the RWP as well as compliance of personnel under his supervision. The supervisor retains and files a copy of the RWP in his office; the original is returned to the Health Physics office where it is kept (Step 7) in the master file of RWPs. As each of the preceding steps is completed, the Master RWP List is annotated to reflect its current status.

Step 8: The operations supervisor is responsible for the execution of this step with the assistance of a member of the Health Physics staff or a Health Physics Technician. During this step, the supervisor will explain to his crew the requirements of the RWP, the importance of adhering to all of its provisions, and his commitment to seeing that each member of his crew carries out the requirements exactly. The Health Physics Staff member is available to explain the technical reasons behind the RWP requirements; but only the Operations Supervisor has the authority (by virtue of his supervisory responsibilities) to direct his crew to comply with the RWP requirements. It is intended that the supervisor's presentation to his crew be supplemented by a video-tape presentation of both the RWP and the associated Standard Operating Procedure (SOP) governing the operation(s) covered by the RWP. Video tapes, where required, will be made available by the Safety Training Officer.

Step 9: At the conclusion of the indoctrination meeting, each operations technician will be required to sign the RWP to signify that he/she fully understands the requirements of the RWP and will comply with those requirements. A copy of each signed RWP will be maintained in the supervisors office; the original will be retained by the Health Physics staff member for filing with the master copy of the RWP in the HP office. The supervisor will also maintain, in his office, a listing of all technicians authorized to work under each work permit over which the supervisor has responsibility.

Steps 10 and 11: The original RWP with signatures produced during Step 7 and 8 will be retained in the Health Physics office. These are important control sheets because they will be used to correlate personnel exposure data against RWPs and to schedule refresher training.

4.2 Monitoring and Audit Procedures

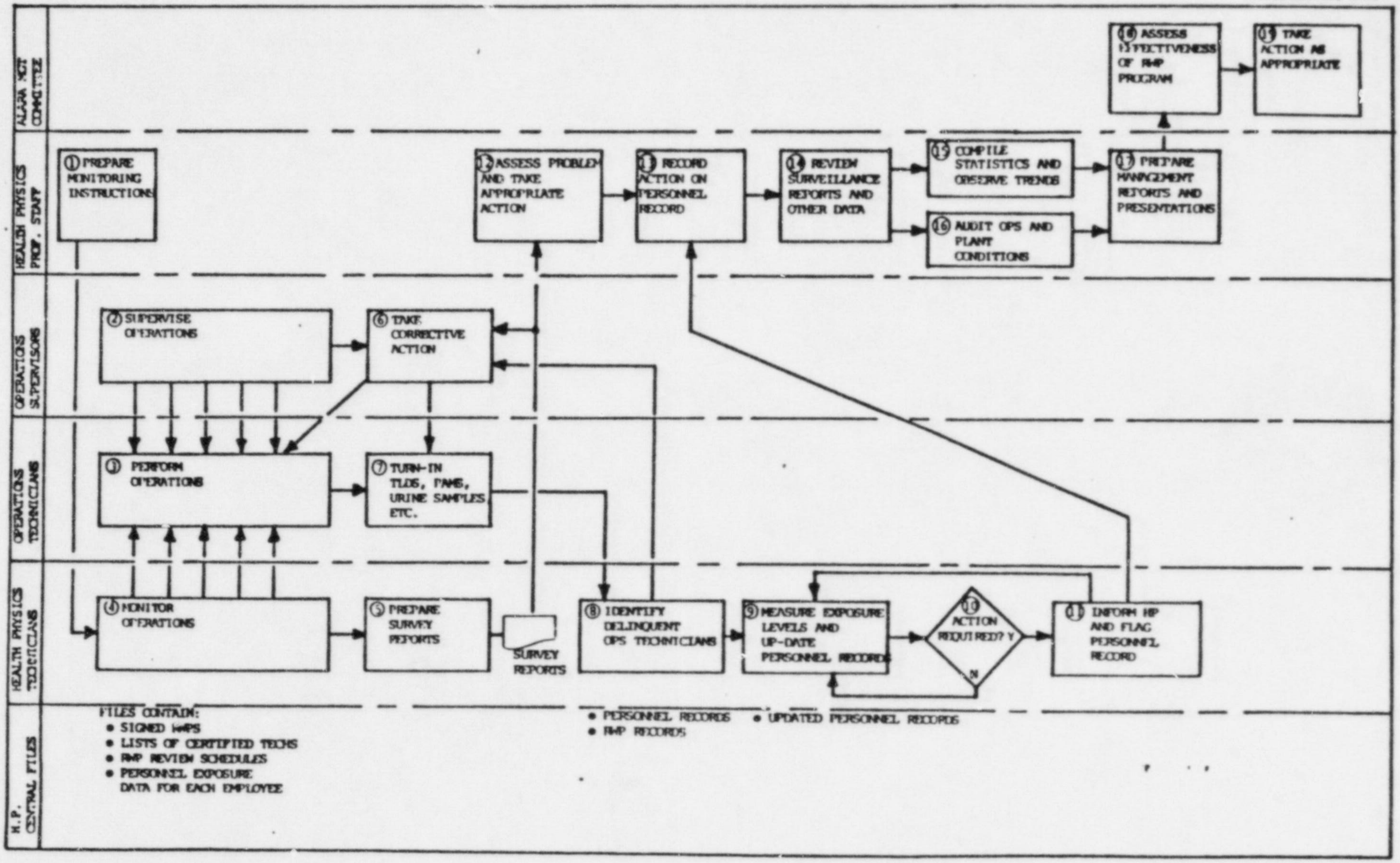
Monitoring and audit procedures included within the NMI Radiological Work Permit System are shown schematically in the flow chart (Figure 4-2). Monitoring of compliance with the requirements of Standing and Special RWPs is accomplished by NMI Health Physics technicians under the direction of an NMI Health Physics Staff member. Audits are conducted by members of the Health Physics Department professional staff both to assess effectiveness of the RWP monitoring program and to assess the effectiveness of RWP safety requirements in maintaining exposure levels ALARA.

a. RWP Monitoring Procedures

Step 1 (Figure 4-2): Monitoring directions are prepared by the Health Physics professional staff from a review of the Standing and Special RWPs in effect. These procedures are given to the responsible Health Physics Staff member who, in turn, passes them on to the Health Physics technicians under his supervision. Special monitoring instructions may be issued for special RWPs. In cases of complex operations (like foundry operations) a full-time monitor may be assigned. Special instructions will usually be issued for monitoring contractor work.

FIGURE 4-2:
MONITORING AND AUDIT PROCEDURES

SEPTEMBER 22, 1983



<u>Steps 2 - 4</u>: HP Technicians monitor operations of manufacturing technicians to assess degree of compliance with requirements of the governing RWPs. Because of the responsibility and accountability commitments made by the operations supervisors (foremen and leadmen) in signing the RWPs, monitoring compliance at the technician level also provides a basis for monitoring effectiveness of manufacturing supervisors in carrying out the requirements of the RWP Program.

<u>Steps 5 and 6</u>: Each floor HP technician files, at the end of his shift, a Radiation Safety Survey Report (Figure 4-3). Violation of RWP requirements are both noted on the report and brought to the attention of the violator and his supervisor. The supervisor may take corrective action (Step 6) if the situation warrants it. Repeated violations are noted by the Manager of the Health Physics Department who can then bring them to the attention of NMI Executive Line Management for their consideration and action.

<u>Steps 7 and 8</u>: RWPs specify any additional exposure monitoring requirements not otherwise in force for all NMI employees working in restricted areas. Such requirements may include urine sampling, daily reading of TLDs, lung counts, etc. It is the responsibility of the manufacturing technicians to observe and comply with these requirements. However, the personnel RWP/Radiation records maintained in the Health Physics central files provide all the information necessary for monitoring compliance with these special requirements. It is the responsibility of the Health Physics laboratory technicians to perform these monitoring functions, in conjunction with their other exposure monitoring duties. Delinquent manufacturing technicians are reported to their supervisors for corrective action as shown by the feedback connection between Step 8 and Step 6 in Figure 4-2. Repeated violations may be cause for the

Figure 4-3

RADIATION SAFETY SURVEY REPORT FORMAT

Name: ______________________________ Date; ____________ Shift: _____

RWP Number	Employee Number	VIOLATION/ACTION

THE REVERSE SIDE OF THIS FORM MAY BE USED FOR ADDITIONAL COMMENTS AND OBSERVATIONS suspension or revocation of a technician's work permit, without which he will be automatically prohibited from performing work within restricted areas.

Steps 9 - 11: The required exposure measurements are taken from Film Badges, TLDs, PAMs, urine samples, etc., by HP Laboratory Technicians, and the results recorded on the personnel RWP records in the HP central files. Updated exposure levels are then compared with the limits set by the controlling RWPs. Whenever exposures approach, or are projected to exceed limits, the personnel record is flagged and the Manager of the Health Physics Department informed so he may take the necessary action with manufacturing line management, Health Services, Personnel, or other departments as appropriate. The RWP and associated monitoring procedures, in conjunction with the centrally maintained RWP and Personnel Files, thus provide a closed-loop system for assuring that all personnel exposure levels are maintained ALARA. Violations of the procedures are readily detectable for remedial action. Note also that the central files which contain copies of each RWP signed by each employee (technician as well as supervisor) provide complete radiological histories with respect to each job that each employee has worked, including special jobs covered by special RWPs, as well as delinquencies in complying with any of the requirements and the remedial actions taken by NMI management. Data within these two centrally maintained files constitutes a basic source of input to the RWP audit process.

b. RWP Audit Procedures (Figure 4-2)

RWP audits serve two basic purposes. The first is to assess the effectiveness of the RWP program and the degree to which compliance with its requirements is actually being achieved. The second is to identify opportunities for further reductions in radiation exposure levels in accordance with the NMI/NRC ALARA philosophy. The RWP audit program is an on-going program where specific audit actions are determined by the staff of the Health Physics Department in concert with NMI management. The generic steps involved in the audit process are shown in Figure 4-2, Steps 14 through 19.

<u>Step 14</u>: The Health Physics staff routinely reviews Radiation Safety Survey Reports submitted by Health Physics floor technicians and personnel exposure records in the Health Physics central files. These two sources of data form the basis for compiling statistics (Step 15) that correlate individual and population exposure levels with RWPs and the associated manufacturing operations. Such correlations help identify areas that warrant detailed examination of alternate ways and means of achieving further reductions in exposure levels or otherwise improving radiation safety through modifications to the governing RWPs.

<u>Step 16</u>: The review of Radiation Safety Survey Reports, by itself, will not necessarily achieve all objectives of the RWP Audit Program, since the survey reports are largely directed toward assuring compliance with the requirements of outstanding RWPs. There remains a continuing need to reassess the appropriateness of the RWPs themselves to the operations they cover. This is accomplished through the systematic auditing of operations and surrounding ambient radiological conditions on a continuous basis by members of the Health Physics professional staff. The periodicity of site audits varies from operation to operation and is scheduled on the basis of the actual and potential radiation hazards associated with the operation -- the most hazardous being audited the most frequently. Audit Reports are prepared following the completion of each audit. Where immediate action is required, it will be taken by revising and issuing new work permits in accordance with the procedures shown

in Figure 4-1. The Survey reports will then be filed with the RWPs in the RWP file for later reference and statistical analysis.

Step 17: NMI executive management is ultimately responsible for the effectiveness of RWP program in achieving NMI/NRC ALARA objectives, through the Health Physics Department which is the RWP Program manager. Management must, therefore, be kept informed of program performance and progress on a regular basis. This function is accomplished by quarterly progress reports prepared by the Health Physics Department and distributed to all members of the ALARA Committee. Contents of the progress reports may include presentation of radiation exposure statistics and trends against all outstanding RWPs, results of audits conducted during the period, and compliance problems that may have existed. Progress Reports may also include numbers and types of Special RWPs that were issued, problems and suggestions requiring ALARA Committee consideration and/or progress with respect to on-going Health Physics RWP projects.

Steps 18 and 19: The ALARA Committee meets quarterly to discuss overall effectiveness of the RWP Program and to identify areas where improvements may be in order. However, ALARA Committee meetings may be requested by Health Physics whenever action may be required that cannot be deferred to the next scheduled quarterly meeting.

5. DATA PROCESSING CONSIDERATIONS

To implement the Radiological Work Permit System, the Health Physics Department must maintain two data files which are readily accessible to the responsible Health Physics Staff member and his staff. The first of these files is the RWP Master File. This file will contain master copies of all RWPs, filed by RWP Number. Associated with each RWP in this file will be a listing of all persons (employees, contractors, visitors, etc.) certified under each RWP, site survey reports, and minutes of planning meetings.

The second file is the RWP Personnel File. This file is organized by person name and contains copies of each RWP signed by that person (organized by RWP Number where possible) and information associated with any RWP suspensions and/or revocations. This file is used to assure that no employee (or other person) exceeds NMI/NRC limits.

Although setting up these files will be relatively straightforward, maintaining consistency between them will be a difficult process, if accomplished manually. Consistency is essential to the success of the RWP Program in maintaining exposure levels ALARA. On the other hand, maintaining consistency would be greatly simplified if the file maintenance process were assisted by ADP. It should be recognized, however, that total automation of files will not be possible because of the need to retain authenticated signatures on RWP hard copy. ADP can assist in the process of maintaining consistency between the hard copy files, in providing early warning of impending exposure problems, and in providing statistical reports.

Initial data processing support will be provided by the automated Personnel File, currently under development by the NMI Data Processing Department. This file will be modified to include RWP numbers for which each person has been certified in each personnel record, thereby correlating the automated Personnel File with the manual RWP File. The possibility of automating the RWP File will be considered at a later date.

APPENDIX A

PRELIMINARY LIST OF EFFECTIVE RWPs

(30 September 1983)

RWP NO.	Title
422-001	Charge Prep
423-001	Shipping
520-001	Billet Assembly
521-001	Extrusion of DU Billets
523-001	Saw Blanks of Depleted Uranium
523-002	Pickling of Depleted Uranium
524-001	Degreasing of Depleted Uranium
525-001	Rotary Straightening of Depleted Uranium (Meeco)
525-002	Aging of Depleted Uranium
525-003	Solutionizing of Depleted Uranium
531-001	Furnace Opening and Disassembly
531-002	Furnace Loading
531-003	Unloading of Castings and Setting-up Molds
531-004	Crucible Burn-Out
531-005	Furnace Rebuilding After A Bad Pour
541-001	Grinding of Depleted Uranium
543-001	Machining of Depleted Uranium - Large Caliber - CNC Lathes
543-002	Preventive Maintenance: Mori Seiki
543-003	Preventive Maintenance: J & L Lathes
543-004	Preventive Maintenance: Max Muller
543-005	Pre-Machining of Depleted Uranium
550-001	Packaging

RWP NO.	Title
560-001	Scrap Packaging
560-002	Consolidation of DU Scrap (S.O.P. No. HWD-83-00)
594-001	Preventive Maintenance: Marvel Saw
594-002	Preventive Maintenance: Crane Inspection
595-001	Preventive Maintenance: Emptying of House Vacuum System Drums
595-002	Filter Change (Not Requiring Entrance Into Filter House)
671-001	Inspection/QC of Depleted Uranium
852-001	Minimum Requirements For Entrance Into Restricted Area

NUCLEAR METALS, INC.

ALARA POLICY

NUCLEAR METALS, INC.

ALARA POLICY

ALARA POLICY

I. Introduction

The purpose of this document is to state the policy of Nuclear Metals, Inc. (NMI) with regard to maintaining occupational radiation exposures as low as is reasonably achievable (ALARA) for all NMI employees and visitors.

The ALARA Program at NMI has been designed to incorporate the philosophy of NRC Regulatory Guide 8.10, Revision 1 to ensure that radiation exposures will be kept ALARA. The management of NMI is firmly committed to ensuring that occupational exposures are kept ALARA. All those who work at NMI, starting with the individual radiation worker, up through the management ranks to the Company President contribute through many available mechanisms toward achieving the fundamental objectives of the ALARA philosophy.

II. Statement of Policy

All persons working at or visiting NMI shall be subject to the rules and standards provided by NMI for radiation protection. These rules and standards of practice at NMI shall incorporate the ALARA philosophy. Specifically, this philosophy, as adopted by NMI, includes a commitment to:

1. Maintain the annual radiation doses to all individual NMI personnel ALARA.
2. Maintain radiation doses to all NMI contractors and visitors ALARA.
3. Maintain the annual integrated radiation dose to all personnel ALARA.
4. Maintain the annual radiation dose to the general public ALARA by appropriate control of environmental releases.

III. Organization, Personnel and Responsibilities

1. President of NMI

The President of NMI is responsible for the execution of a Company-wide Radiation Protection Program and assures that the policies and commitments contained in the program are being properly implemented.

2. ALARA Committee

The responsibility to review and audit ALARA efforts of the Radiation Protection Program is assigned to the ALARA Committee. The Committee consists of personnel who are experienced and knowledgeable of Health Physics principles, practices and procedures and who are familiar with design features and operations of NMI which affect the potential for exposures of personnel and the environment to radiation. The ALARA Committee is responsible to the President of NMI.

The personnel listed below will serve on the ALARA Committee. Any two (2) members below and a Vice President will constitute a quorum and be sufficient to convene the Committee to make dose reduction policy decisions. The ALARA Committee will meet at least quarterly, but more frequently if necessary.

ALARA Committee Members:

1. Vice President, Health/Safety
2. Vice President, Operations
3. Vice President, Facilities
4. Manager, Health and Radiation Safety
5. Manager, Human Resources
6. Health Physicist/Dosimetry
7. Safety Training Officer

The responsibilities and authorities of the ALARA Committee include the following:

1. Ensuring that the NMI Radiation Protection Program to keep radiation exposures ALARA integrates management's philosophy and regulatory requirements and is maintained with specific goals and objectives for implementation.
2. Ensuring that an effective dose measurement system is maintained and used to determine the degree of success achieved in NMI operations with regard to the ALARA goals and specific objectives.
3. Ensuring that the dose measurement system results are reviewed on a periodic basis by the Radiation Protection staff and that corrective action is taken when attainment of the ALARA objectives appears to be jeopardized.
4. Ensuring that the authority for providing procedures and practices by which the specific goals and objectives will be achieved is delegated.

5. Ensuring that the resources needed to achieve ALARA goals and objectives are made available following acceptable financial review (i.e., cost/benefit analysis).

In support of the above, the ALARA Committee will undertake such activities as:

1. The review of selected ALARA-related procedures and major sources of exposure with the intent of identifying means for their reduction.

2. Review the details of any exposures near or over applicable regulatory limits or other abnormal occurrences involving occupational radiation exposure hazards and the corrective actions taken to prevent their recurrence.

3. Verification of the adequacy of ALARA training conducted by the Radiation Protection staff and the Safety Training Officer.

4. Review design changes identified as potentially having a significant effect on radiation exposures.

The Committee serves as a review and advisory group whose primary function is to verify that a satisfactory ALARA Program is in effect and incorporated into the Company's Radiation Protection Program. Company management and supervision shall be responsible to the recommendations of the ALARA Committee.

3. <u>ALARA Committee Members</u>

a. <u>Vice President, Health/Safety</u>

The Vice President, Health/Safety is responsible for all regulatory licensing applicable to NMI in the area of radiation safety. He is also responsible for overall administration of programs, including the Radiation Protection Program, Occupational Safety Program and the Environmental Surveillance Program. His responsibilities include:

1. Participating in design reviews for NMI facilities and equipment that can affect potential radiation exposures.

2. Prescribing goals and objectives to be achieved in the Radiation Protection Program.

3. Developing and optimizing a Radiation Exposure Control Program for NMI.

4. Review safety inspection records to determine consistency with the NMI ALARA policy.

b. Vice President, Operations

The Vice President, Operations is responsible for the overall administration of the manufacturing process and its related operations. His responsibilities with respect to the ALARA Committee are as follows:

1. Participating in process reviews of NMI manufacturing and other operations that can affect potential radiation exposures.

2. Ensuring the support for the NMI Radiation Protection Program from all manufacturing personnel.

3. Supporting the Manager, Health and Radiation Safety in effective implementation of the Radiation Protection Program.

4. Specifying goals and objectives for NMI operations which incorporate the ALARA philosophy.

c. Vice President, Facilities

The Vice President, Facilities ensures that criteria affecting potential radiation exposures and radioactive contamination are considered in the design and construction of facilities and equipment. With respect to the ALARA Committee, his responsibilities include:

1. Review of all equipment and facility designs to insure that the potential for causing significant radiation exposures is minimized.

2. Review of any modifications of current equipment or facilities to ensure that the potential for causing significant radiation exposures is minimized.

3. Ensure that NMI Facility Engineers be aware of ALARA objectives and incorporate these objectives when designing, installing or retrofitting equipment or facilities which process radioactive materials.

d. Manager, Health and Radiation Safety

The Manager, Health and Radiation Safety is responsible for implementation and optimization of the Radiation Protection Program. He is responsible for ensuring adequate radiation protection for all NMI and non-NMI employees. The Manager, Health and Radiation Safety's responsibilities include:

1. Ensuring that all operations involving work with radioactive materials is supported by adequate physical presence of Health Physics personnel.

2. Supervising, training and qualifying the radiation protection staff under his supervision.

3. Identifying locations, operations and conditions that have the potential for causing significant exposures to radiation.

4. Implementing and maintaining an adequate Radiation Exposure Control Program for all NMI employees and visitors.

5. Developing plans, procedures and methods for keeping radiation exposures of NMI employees and visitors ALARA.

6. Reviewing, commenting on and recommending changes in job procedures to maintain occupational exposures ALARA.

7. Participating in the development and approval of Training Programs related to work in radiation areas or involving radioactive materials.

8. Supervising the collection, analysis and evaluation of data and information obtained from radiological surveys and environmental activities.

e. <u>Manager, Human Resources</u>

The Manager, Human Resources is responsible for the administration and implementation of Personnel Policies and Procedures. His responsibilities as they relate to the ALARA Committee are as follows:

1. Ensure that ALARA objectives as they relate to individuals are implemented in a fair and equitable manner.

2. Ensure that ALARA decisions incorporate the "human factor" as an integral part of the decision making process in addition to financial considerations and cost benefit analysis.

f. <u>Health Physicist/Dosimetry</u>

This Radiation Protection staff professional is responsible for NMI's Radiation Dosimetry Program. He supports the Manager, Health and Radiation Safety in ensuring adequate radiation protection for all NMI personnel and visitors. His specific responsibilities as they relate to the ALARA Committee are as follows:

1. Presenting to the ALARA Committee the results of NMI's dose measurement system.

2. Ensuring that results obtained from NMI's dose measurement system are technically sound and accurate.

3. Identifying locations, operations and conditions which have the potential for causing significant exposures to radiation.

4. Reviewing and recommending changes in standard operating procedures to maintain occupational exposures ALARA.

5. Participating in the development and implementation of Training Programs related to work in radiation areas or involving radioactive materials.

6. Conducting special investigations of radiation exposures which are near or over established in-house and regulatory limits.

g. Safety Training Officer

The Safety Training Officer is responsible for the overall development and implementation of a Safety Training Program. This program encompasses the initial orientation for all NMI employees and visitors regarding radiation safety. His responsibilities as they relate to and support the ALARA Committee are as follows:

1. Development of Employee Training Programs which entail both introductory orientations and retraining efforts dealing with the health protection problems associated with radioactive materials.

2. Presenting and emphasizing the importance of exposure reduction efforts to all employees and visitors.

3. Ensure through employee education an understanding of the basic concepts of radiation protection such as time, distance and shielding.

4. Development and implementation of employee training sessions where the ALARA concept is viewed as an attitude and commitment to enhanced radiation protection.

4. Department Managers

Managers of individual departments at NMI are responsible for:

1. Ensuring support for the NMI Radiation Protection Program from all of their personnel.

2. Specifying goals and objectives for NMI operations that incorporate the objectives of the Radiation Protection Program.

3. Supporting the Manager, Health and Radiation Safety in formulating and implementing the Radiation Protection Program.

4. Identifying locations, operations and conditions that have the potential for causing significant exposures to radiation.

5. Individual NMI Employees

Each individual who performs a work assignment within a restricted area and who is likely to receive an occupational radiation exposure becomes subject to the rules and policies of the Radiation Protection Program. Each individual is responsible to comply with NMI policy as set forth in operating procedures, Radiation Work Permits and NMI's Personnel Policy Manual.

IV. Training and Instruction

A Training Program in the fundamentals of radiation protection and exposure control has been established by NMI. It includes instruction of all personnel whose duties require:

1. Work with radioactive materials.

2. Entering radiation areas.

3. Directing the activities of others who work with radioactive materials or enter radiation areas. The training includes sufficient instruction in the biological effects of exposure to radiation to permit the individuals receiving instructions to understand and evaluate the significance of radiation doses in terms of potential risks.

Training sessions are held for the purpose of employee orientation. These introductory orientations deal with the health protection problems associated with exposure to radioactive materials. An overview of basic radiation safety is presented, as well as specific safety concerns relating to work with Depleted Uranium.

In addition to the introductory orientation, all operating personnel are observed by their department foremen who work with employees on a continuing basis to assure proper orientation to the hazards of the workplace. The above will be supplemented by an ongoing monitoring program by the Health Physics technical staff with respect to procedures to minimize exposures such as monitoring or measurement techniques which may be employed to determine the level of exposure and corrective actions. Should an employee be found to have poor work habits which contribute to additional, unnecessary exposure, he/she will be instructed to sit in on the next refresher training session. Employees who are required to be retrained due to poor working habits will be monitored closely until all procedures are performed in accordance with the ALARA philosophy.

All employees are required to take part in an annual retraining program. The Training Officer conducts refresher training sessions which encompass the specific characteristics and concerns of ionizing radiation, the concept of ALARA as a fundamental principle of radiation protection and how it can be implemented on the job. The program discusses the proper use of change areas, ventilation and general contamination limits and control. Active participation of each individual employee is encouraged. Basic concepts of radiation protection such as time, distance and shielding are set forth and discussed. The employee is urged not just to view ALARA as a concept, but rather, an attitude and a commitment to improved radiation protection in order to maintain exposures ALARA.

Training is commensurate with the duties and responsibilities of those receiving instructions, as well as with the magnitude of potential and anticipated doses and dose rates. Personnel who direct activities of others who may be exposed to radiation shall be familiar with NMI's Radiation Protection Program and have the authority to implement NMI's policy to ensure that exposures to personnel will be as low as reasonably achievable.

V. Radiation Protection Program

The management of Nuclear Metals, Inc. recognizes its responsibility to its employees, to the public and to the environment to maintain a Radiation Protection Program which will result in the highest attainable level of safety and protection from radiation.

The Radiation Protection Program at NMI consists of a comprehensive set of policies and procedures which ensure that radiation exposures will be kept ALARA for all NMI employees, contract personnel, visitors, the general public and the environment.

Administrative controls have been established as to the amounts of radiation exposures that may be accumulated by any employee, to ensure that the limits governing personnel exposure delineated in 10 CFR 20 and applicable State regulations are not exceeded.

NMI recognizes that substantial reductions in radiation exposure can be afforded by features that are built into the design of equipment used in production areas or used in handling radioactive materials. Its Radiation Protection Program also includes procedures, job planning, recordkeeping, operating philosophy, special equipment and operational analyses.

As part of NMI's operating philosophy, NMI employees will have the benefit of preparations and planning that will consider the following requirements and criteria.

1. The Health Physics Department will have the responsibility for coordinating ALARA efforts in support of operations to reduce radiation exposures.

2. Surveys will be performed to obtain information with respect to ambient radiation levels, contamination levels and concentrations of airborne radioactive material that might be encountered during routine operations and other non-routine operations being performed.

3. Radiation surveys will provide favorable locations for personnel to take advantage of available shielding, distance and other factors that affect the magnitude of the radiation dose.

4. Preplan meetings for personnel who will perform non-routine work in radiation areas.

5. Reducing the levels of radiation by appropriate decontamination methods.

6. Provide radiation monitoring instruments and provide routine instrument calibrations in accordance with existing procedures.

7. Use will be made of Radiation Work Permits to provide advance planning for non-routine maintenance work.

8. Unusual occurrences and potential accident situations will be monitored for information to be used in planning for such occurrences.

9. Temporary shielding will be used where practicable.

10. Portable or temporary ventilation systems will be used where practicable.

11. Use will be made to the extent practicable of a comfortable work environment to increase efficiency and thereby reduce the amount of time spent in radiation areas.

During operations in radiation areas, adequate supervision and radiation surveillance will be provided to ensure that the appropriate procedures are followed. This will include the following:

1. Assigning a Health Physics Technician the responsibility of periodically monitoring all work areas where radioactive materials are processed, handled or stored.

2. The use of personnel dosimeters (TLD or Film Badges) to provide monitoring of doses to individuals.

3. The use of written procedures and verbal instructions between all personnel and the Health Physics Department.

Observations, experience and data obtained during routine and non-routine operations will be recorded and analyzed to identify deficiencies in the program and provide bases for revising procedures that may reduce exposures during similar operations. This will include the following:

1. Exposure obtained during an operation will be recorded.

2. Component failures that resulted in the need for servicing will be analyzed in order to improve equipment reliability.

3. Information gained during operations will be used as part of a continuous evaluation of equipment to provide bases for modifying equipment selection and design features of new facilities.

4. Summaries of doses received will be reviewed periodically by upper management to compare the incremental reduction of doses with the cost of modifications that could be made.

VI. Facility and Equipment Design Features

NMI engineers will consider the levels of radiation that can be expected in order to design features into the equipment that will keep radiation exposures as low as reasonably achievable. When designing or modifying equipment, the following factors will be considered:

1. Access control of radiation areas

2. Radiation shielding

3. Process instrumentation and controls

4. Control of airborne contaminants

5. Isolation and decontamination

6. Radiation monitoring systems

Any design that involves application in a radiation environment shall be reviewed and approved by a member of the Health Physics professional staff.

VII. Review of New or Modified Designs and Selection of Equipment

Several groups within NMI may have an interest in equipment design and selection. These groups (i.e., Maintenance, Operations, Health

Physics, Safety and Engineering) will be adequately represented at the time a design is reviewed or equipment is being selected to ensure that ALARA objectives will be achieved.

Radiation aspects of decommissioning should be factored into planning, designing, construction and modification activities. NMI design features should provide for the reduction of anticipated exposures to personnel to the extent practicable.

Specifications for equipment should reflect the objectives of the ALARA policy, including considerations of reliability, serviceability, limitations of internal accumulations of radioactive materials and other features.

Replacement equipment should reflect modifications based on experience gained from using the original equipment.

VIII. Radiation Protection Facilities, Instrumentation and Equipment

The Health Physics staff will be furnished with facilities, instrumentation and protective equipment adequate to permit the staff to function efficiently in maintaining radiation exposures ALARA. Instrumentation and other equipment will be adequate to meet normal operating needs as well as any emergency situations which may require supplemental workers and/or extensive work in radiation areas.

NMI will provide the Health Physics staff with the following equipment and instrumentation to ensure radiation protection for NMI personnel, NMI contractors, the general public and the environment:

1. Counting room facilities to facilitate the qualitative and quantitative analysis of air, soil, vegetation, water, urine and other necessary samples.

2. Portable instruments to detect and measure alpha, beta and gamma radiation and where applicable, dose rates, ambient air concentrations and contamination levels.

3. Personnel monitoring instrumentation, including film badges and/or thermoluminescent dosimeters.

4. Protective equipment, including protective clothing and respiratory protection equipment.

5. Support facilities to ensure adequate implementation of the Radiation Protection Program.

6. Any other ancillary equipment needed to improve the overall Radiation Protection Program.

February 17, 1984

U. S. Nuclear Regulatory Commission
Region I
631 Park Avenue
King of Prussia, PA 19406

Attention: Thomas T. Martin, Director
Division of Engineering
and Technical Programs

Re: Docket No. 40-00672
CAL No. 83-08 dated 5 August 1983
Your letter dated 17 January 1984

Gentlemen:

In response to your letter dated 17 January 1984, Nuclear Metals, Inc. (NMI) is submitting a revised program and format for the performance of audits of radiological work practices. This revision represents the mechanisms by which identified findings will receive prompt management action and review. Additionally, the revised documentation is such that implementation of corrective actions for inappropriate work practice(s), where and when deemed necessary, will be assured by written communication and additional management review. The revised Audit Program has been incorporated with the five elements, identified in your recent letter, in mind.

Attached you will find a copy of a memorandum regarding our revised Audit Program. Within the memorandum is:

(1). Instructions for Health Physics Staff members to use in performing radiological audits.

(2). A written plan of the area(s) to be reviewed.

(3). A sample Audit Checklist which is used to report audit findings.

The Audit Checklist which is used to report audit findings serves several functions. A few of these functions are listed below:

(1). It details the depth of review necessary to complete an audit.

(2). When distributed, it initiates corrective action(s) and indicates the timetable for these actions to be completed.

(3). It serves to identify the need for follow-up review/audits.

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2229 Main Street, Concord, Massachusetts 01742 (617) 369-5410

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Attachment No. 2 is an example of a completed audit under our revised program. We believe that this revised Audit Program meets the intent of Item 1 of the August 5, 1983 Confirmatory Action Letter (CAL No. 83-08) and your letter dated January 17, 1984.

If you have any questions regarding this submission, please feel free to contact us.

Sincerely,

Frank J. Vumbaco

Frank J. Vumbaco, Manager
Health and Radiation Safety

FJV/DJA:aj

Attachments

CC: Mr. Joseph C. Wang
U. S. Nuclear Regulatory Commission
Material Licensing Branch
Division of Fuel Cycle and Material Safety
Washington, D. C. 20555

ATTACHMENT NO. 1

OFFICE MEMORANDUM

Nuclear Metals Inc.

to: Distribution

date: 2-13-84

from: F. J. Vumbaco FJV / D. J. Allard DJA

subject: INSTRUCTIONS FOR NMI HEALTH PHYSICS STAFF AUDITS

Purpose:

The purpose of a Health Physics Staff Audit is to assure, on a rotational basis, that each area of the Concord facility is inspected in-depth by a member of the Health Physics Professional Staff with respect to radiological hazards. Furthermore, this program assures that an identified hazard is documented, evaluated, and corrected by all parties involved. It should be stressed that the Health Physics Department can immediately shutdown any operation that does not comply with NRC regulations or the NMI Source Material license and its respective conditions.

Logistics:

Each day during the work week, a Health Physics Staff member shall tour the Concord facility for a minimum of two hours. The tour assignments are for one week, with Health Physics Staff members rotating on a scheduled basis. For one day of the assigned week the Staff member shall perform a detailed evaluation of a single area. The extent of the audit will depend on the nature of the operations performed. The audit may take from two hours to the entire day. Staff members should review the Standing Radiation Work Permit (RWP) for the area/operation prior to the actual audit. In the case of a non-routine operation, the staff member should arrange to be notified such that he/she may audit the Special RWP and operation. Table I which is attached outlines areas that shall be sequentially audited on a rotating basis. The Health Physics Technical Assistant will maintain all audit files and forms.

The actual audit observations shall be recorded on the NMI Health Physics Staff Audit Checklist. The Auditor (Health Physics Staff member) shall minimally complete the list of items on the Audit Checklist. If applicable, monitoring such as ambient field surveys, air sampling, or random smears for contamination control should be performed to audit engineering controls and/or suspect operations/procedures.

In the event that an item of non-compliance is observed, the Auditor shall (1) describe the problem and make recommendations for corrective action(s) on the Audit Checklist form, (2) indicate corrective action(s) required and a timetable for implementation on the Audit Checklist form, (3) bring the situation to the attention of the responsible parties through verbal communication, and (4) distribute the checklist copies to the responsible parties for appropriate action and documentation. The means by which follow-up will be accomplished will depend upon the nature of the problem but this mechanism shall be indicated on the Audit Checklist prior to sign-off (i.e., by employee, Area Supervisor and Health Physics Staff Auditor).

Follow-up:

All Health Physics Staff Audit Checklists shall be reviewed during regularly scheduled Health Physics Staff Meetings. Recently closed items (i.e., since the last Staff Meeting), currently open items, and past open items (i.e., for update) shall be reviewed. This is in addition to routine tour observations in other areas. Should the Health Physics Department conclude that an item cannot be resolved internally or in a timely fashion, it shall be scheduled for review at the next meeting of the ALARA Committee for disposition.

The Health Physics Technical Assistant shall keep Staff Meeting Minutes and the Audit Checklist files by area (open and closed separately). No item shall be filed as closed until it has been reviewed in a subsequent Health Physics Staff Meeting. All documentation (i.e., additional audits, measurements, memoranda, engineering designs, etc.) shall be attached to the original Audit Checklist.

APPROVED: (A. R. Gilman) APPROVED: (F. J. Vumbaco)

FJV/DJA:aj

Attachment: Audit Checklist form

Distribution: A. R. Gilman, R. B. MacKay, D. Ferguson, W. Burmeister, G. A. Clattenburg, P. Loewenstein, H. F. Sawyer, B. E. Eveland, F. J. Vumbaco, R. P. Harding, K. Fogarty, T. Carpenito, J. Lischinsky, A. Joseph, File

TABLE I

SPECIFIED AREAS BY PROCESS FLOW FOR RADIOLOGICAL STAFF AUDITS

AREA	RWP NUMBER (Where Applicable)
1). Shipping and Receiving	423-001
2). Charge Preparation	422-001
3). Foundry	
a). Melting/Casting (Ordnance)	531-001, 002, 003
b). Melting/Casting (Commercial)	531-001, 002, 003
c). Crucible Burn-out	531-004
d). Crucible Cleaning	531-001, 002, 003
e). Scrap Cutting: Saw	523-001
f). Furnace Rebuilding	531-005
4). Billet Assembly/Canning	520-001
5). Extrusion: 1400 Ton Press	521-001
6). Blank Cutting: Saw	523-001
7). Acid Pickling	532-002
8). Heat Treat	
a). "D" Building Furnace(s)	525-002, 003
b). Mezzanine Furnace(s)	525-002
c). Degreasing of DU	524-001
9). Rotary Straightening	525-001
10). Machining: Max Mueller Rough Turning	543-005
11). Machining: Max Mueller Finish Turning	543-001
12). Machining: CNC Finish Turning	543-001
13). Machining: J & L Finish Turning	543-001
14). Machining: Multi-Spindle Rough Turning	543-005
15). Machining: CAF Finish Turning	
a). Dubied Lathes	543-001
b). Traub Lathes	543-001
c). Duap Lathes	543-001

TABLE I
SPECIFIED AREAS BY PROCESS FLOW FOR RADIOLOGICAL AUDITS
Page 2

AREA	RWP NUMBER (Where Applicable)
16). Machining: Machine Shop	
a). Commercial Lathes	543-001
b). Cutting: Saw	523-001
17). Machining: Machine Shop Annex	
a). Grinders	541-001
b). Cut-off Wheels	541-001
c). CNC Lathe	543-001
d). Shear	543-001
e). Cabinet Grinder	541-001
18). Operational Support	
a). Quality Control	
- In-process (Various Machining Areas)	671-001
- Final	671-001
b). Weld Shop	
c). Stockroom	
d). Metallurgy Laboratory	
e). Engineering Services Laboratory	
f). Maintenance	
- Routine (i.e., Roof Filter Change)	595-002
- Special (i.e., Machine/Equipment Repair)	
g). Sheet Metal Shop	
h). Graphite Shop	
19). Scrap Handling	560-001, 002
a). Compactors	
b). Concrete Encapsulation	
c). Bricketting	
20). Packaging (Product)	550-001
21). Other Areas	
a). Offices	
b). Cafeteria	
c). Shoe Change Areas	852-001
d). Personnel Entrance/Exit Area	
e). Locker Room(s)	
f). Corridors (Hallways)	
g). Non-DU Processing Areas (i.e., REPs, Superalloy, Be)	

ATTACHMENT NO. 2

NUCLEAR METALS, INC: HEALTH PHYSICS AUDIT CHECKLIST

Auditor: ____________________ Date/Time: ____________ LOCATION: ________________

Brief description of operation: ____

____

____

Personnel Items:	O.K.	Facility Items:	O.K.
Adherence to RWPs and SOPs	____	Ventilation Operational	____
Dosimetry	____	Equipment Function	____
Protective Clothing	____	DU Waste Control	____
Safety Glasses	____	DU Storage	____
Safety Shoes/Shoe Covers	____	Sumps/DU Sludge	____
Smoking/Eating/Drinking	____	Contamination Control	____
Respirator Use	____	Survey Meters	____
PAM Use	____	Signs/Alarms	____
Proper Use of Equipment	____	Air Samplers (Stationary)	____
Contamination (Clothing/Skin)	____	Fire Extinguishers	____
Change Area/Washing/Monitoring	____	Misc. Safety (Electrical/Mechanical)	____
Other: ____________	____	Other: ____________	____

Measurement Results (if applicable):

Location	Rate/Conc.( )	Est. Exposure Time	Est. Exposure
________	________	________	________
________	________	________	________

Comments/Recommendations:

____

____

____

Planned Corrective Action(s) and Timetable:

____

____

____

Sign Off: I have reviewed the above and agree to the Corrective Action Plan.

________________ (Employee) ________________ (Area Supervisor) ________________ (Auditor)

Follow-up: Circle One or More Below. Date Closed: __________ (Attach Proper Documentation)

None Needed Closed | By Auditor Open | By Next HP Staff Auditor Open | By Area Supervisor Open

Engineering Control Study Needed/Open | Other: Open ________________________________

White Copy: File | Green Copy: Area Supervisor | Yellow Copy: Area Vice President

Pink Copy: A. R. Gilman | Gold Copy: F. J. Vumbaco

ATTACHMENT No. 2

NUCLEAR METALS, INC: HEALTH PHYSICS AUDIT CHECKLIST Shipping/Receiving

Auditor: David J. Allard Date/Time: 2/17/84; 11AM LOCATION: Butler 2 Bldg.

Brief description of operation: Ship and Receive facility materials, equipment and product (RWP # 423-001)

Personnel Items:	O.K.	Facility Items:			O.K.
			Removable		
			dpm α / 100 cm²	dpm β / 100 cm²	
Adherence to RWPs and SOPs	✓	Ventilation Operational			N/A
Dosimetry	✓	Equipment Function			✓
Protective Clothing	✓	DU Waste Control			N/A
Safety Glasses	✓	DU Storage			✓
Safety Shoes/Shoe Covers	✓	Sumps/DU Sludge	Off. <LLD	<LLD	N/A
Smoking/Eating/Drinking	✓	Contamination Control			✓
Respirator Use	N/A	Survey Meters	Pac. Area 12	71	✓
PAM Use	N/A	Signs/Alarms			✓
Proper Use of Equipment	✓	Air Samplers (Stationary)			N/A
Contamination (Clothing/Skin)	✓	Fire Extinguishers			✓
Change Area/Washing/Monitoring	✓	Misc. Safety (Electrical/Mechanical)			✓
Other:		Other:			

Measurement Results (if applicable):

LLDα ~10 dpm
LLDβ ~30 dpm

Location	Rate/Conc. ( )	Est. Exposure Time	Est. Exposure
Office	0.02 to 0.2 mR h⁻¹ (gamma)	6 hr/day	~ 80 mrem/quart.
Packaging Desk	0.15 mR h⁻¹		

Comments/Recommendations:

Survey meter used for ship/Rec. surveys ok (Batt. OK, Cal. date OK). Reviewed: monitoring methods; shipping papers (bill lading, licence of recievers, 741 transaction reports, smear data), procedures with compliance tech; All ok. Fire cart present (Scott Air pacs - 2, CO_2 - 2, metal-x-2, H_2O-1) which was safety checked 2/8/84.

Planned Corrective Action(s) and Timetable:

None

Sign Off: I have reviewed the above and agree to the Corrective Action Plan.

N/A (Employee) N/A (Area Supervisor) David J. Allard (Auditor)

Follow-up: Circle One or More Below. Date Closed: ________ (Attach Proper Documentation)

(circled) None Needed Closed | By Auditor Open | By Next HP Staff Auditor Open | By Area Supervisor Open

Engineering Control Study Needed/Open | Other: Open

White Copy: File | Green Copy: Area Supervisor | Yellow Copy: Area Vice President
Pink Copy: A. R. Gilman | Gold Copy: F. J. Vumbaco