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Amersham
QSA

Mr. Charles W. Hehl, Director
Division of Radiation Safety and Safeguards
USNRC
Region I
474 Allendale Road
King of Prussia, PA 19406

13 May 1995

Dear Mr. Hehl:

On March 29, 1995, two inspectors made an on site review of " hot particle skin contamination incidents" that had occurred over the past several years at our facility. Subsequently, on 18 April 1995, Amersham received the NRC's inspection report dated 13 April 1995.

Upon review of the inspection report we discovered a number of inaccuracies. Consequently and pursuant to our request, a telephone conference call with Dr. Shanbaky and Ms. Lanzisera was held to discuss these matters on 24 April 1995. Since prior conversations with Region I staff members indicated that NRC had concerns beyond those associated with the two apparent violations, the nature of these concerns and whether they were to be reviewed at the enforcement conference was also discussed during this conference call.

Based on the information Amersham provided during the 24 April 1995 telephone conference call, the NRC staff requested that we submit our understanding of the special inspection report inaccuracies. We provide this information as Attachment 1.

Please note that one of the inaccuracies relates to information we consider to be proprietary. As such, and in accordance with 10 CFR 2.790, we have described this information in a separate appendix (Appendix 4), and included the requisite affidavit requesting that the information is withheld from public access.

To ensure that the formal record is accurate, we respectfully request that a revised inspection report or errata sheet(s) be transmitted to us at your earliest convenience.

Enclosure (3)

We have reviewed and evaluated the activity assessment for the reported overexposure, and based on these findings have performed a final dose reassessment for the incident. This is included as Appendix 1. Please note that Appendix 1 and it's attachments includes references to named individuals and should also be withheld from public access.

We appreciate the opportunity to discuss the contents of this letter and its attachments to assure there is full understanding by ourselves and NRC of all the issues. This will allow us to continue to maintain our excellent safety record.

William M. McDaniel
Burlington Site Manager

Attachment 1

Our review of the NRC Special Inspection report reveals the following inaccuracies. These inaccuracies were discussed by phone with Dr. Shanbaky and Ms. Lanzisera on 24 April 1995.

PAGE/PARAGRAPH	INACCURACY
2/1	NRC statement: "After all the ampoules are removed and opened, the shipping container is lowered out of the cell and a lead plug is placed to seal the cell."
2/2	Amersham's response: The 702 (shipping cask) is removed from the unloading cell after all the unopened 849 capsules are removed from the 702. No capsules are cut open until the 702 is brought down and the plug is reinserted into the bottom of the cell. This is to minimize potential for transfer of contamination. Cleaning of wafers is performed as needed on the raw material, after opening of the 849 capsule. The cleaning is performed to minimize the transfer of contamination to the loading cells.
2/3	NRC Statement: "The licensee stated that the hot particle contamination started to appear in 1991, and coincided with a change of wafer suppliers." Amersham's Response: Iridium contamination did not originate in 1991 as a result of a change is suppliers. Prior to 1991 contamination events were not routinely documented. Beginning in 1992 enhanced record keeping requirements and employee awareness resulted in an increase of reported contamination events. There were also many other factors that occurred which contributed to the increase in reported events, these include; additional personnel being trained in operations that occur in the contamination control area, a wider variety of suppliers of the raw

Ir-192 resulting in varying degrees of quality of the material and an increase in the amount of material handled.

It is difficult to define any one factor that caused the documented increases in contamination events. It is probably due to a combination of all the factors described.

2/3 NRC Statement:

"The licensee stated that the wafers frequently arrived with significant contamination in the form of small particles of iridium on the surfaces of the wafers that are activated during wafer manufacture and become hot particles."

Amersham's Response:

The contamination is not primarily due to the presence of Ir particles on the wafers prior to irradiation. The wafers tend to be fairly clean of particulate matter prior to being irradiated. After irradiation, the wafers are brittle which makes them susceptible to flaking and breaking during transport and handling. Variations in loose contamination levels can be influenced by many factors including: transport time, irradiation time, cleaning processes used, thickness of wafers, handling techniques, etc.

2/3 NRC Statement:

"The licensee stated that these particles have led to extensive contamination of the inside of the hot cell."

Amersham's Response:

One of the primary purposes of the unloading cell is to remove significant levels of contamination before it gets to the loading cells, which are used on a daily basis for 8 hours a day. The unloading cell is therefore performing its function as intended.

We have seen an increase in the radiation levels inside the unloading cell after receiving material with higher than normal loose contamination. This level increased through 1993 and has leveled off to remain fairly constant during 1994 and 1995.

2/3 NRC Statement:

"Various instruments, such as Eberline Model E-120 with HP-210 probe, Ludlum Model 3 with 44-40 probe, Ludlum Model 2221 with 44-40 probe and Ortec sodium iodide detector are used for personnel contamination surveys."

Amersham's Response:

The Ortec sodium iodide detector is a well counter and is used for the assay of wipes and for activity assessment of particles. It is not used for personnel contamination surveys.

3/1 NRC Statement:

"A portal monitor (hand and shoe) is used to monitor personnel leaving the Hot Laboratory."

Amersham's Response:

A portal monitor is used when leaving the contamination control area of the Radioisotope Laboratory, not the entire lab.

The portal monitor is not a hand and shoe model, it detects contamination on the upper and lower leg, the upper and lower arm and the head in addition to the hands and feet. The portal is used as a preliminary screen not a clearing frisk. A full frisk is performed after the portal monitor as a requirement to clear from the area.

4/1 NRC statement:

"The licensee stated that skin contamination incidents were observed in 1991 when the supplier for Ir-192 wafers was changed."

Amersham's Response:

See response to 2/3.

4/1 NRC Statement:

"All skin contamination incidents are considered by the licensee to be hot particle contamination, because encapsulation work with the

metallic materials results in discrete particles of licensed materials contaminating work areas.

Amersham's Response:

The skin contamination is considered to be hot particle because the contamination meets the definition of hot particle given in NCRP 106 and in the NRC information notice 90-48.

The statement in the inspection report seems to imply that the actual encapsulation work creates the hot particles. As described in the response to 2/3, the irradiated Ir-192 wafers are the source of the hot particles.

4/2 NRC Statement:

"Employees from the hot laboratory use a hand/shoe portal monitor when exiting the facility and frisk themselves with either an Ortec NaI detector or a Ludlum Model 2221 survey meter with a 44-40 shielded pancake probe to detect particles on clothing or skin."

Amersham's Response:

The Ortec NaI detector is not used for personnel contamination surveys. The model Ludlum 2221 was purchased specifically to obtain greater accuracy in assessing contamination activity in place and is not generally used for frisking. General frisking is performed using a variety of GM friskers.

4/3 NRC Statement:

"Attempts to remove the source for counting in a well counter failed, but the contamination was removed after repeated washings of the shirt."

Amersham's Response:

The initial attempts to remove the particle were performed using tape. Although this technique had been used successfully in the past, it did not remove the particle from the shirt in this case. The next technique used consisted of rinsing small amounts of liquid through the shirt fibers and catching the liquid and contamination on the opposite side of the shirt with Kimwipes. This technique was successful in removing

all of the contamination from the shirt. The kimwipes were then evaluated in a NaI well counter for activity determination.

5/1 NRC Statement:

"The licensee's methods of dose assessment were reviewed during the inspection to verify the adequacy of the licensee's methodology in assessing exposures to hot particles and subsequent radiological control actions taken as a result of the licensee's assessment."

Amersham's Response:

The inspectors were on site for approximately 4 hours and although there were general comments made on dead time and attenuation considerations, a detailed review of dose assessment did not appear to take place during the inspection.

It is unclear to what degree a detailed assessment was performed by the inspectors while on site pertaining to the subsequent radiological control actions taken. It is not clear if this statement relates specifically to the actions taken after the reported incident or actions in general to implement radiological controls for hot particles. There have been many actions taken in general to reduce the spread of contamination, these were not discussed with the inspectors in detail during the inspection. A list of the routine procedures are included in Appendix 2.

5/2 NRC Statement:

"The inspectors also reviewed hot particle contamination incidents that have occurred since 1991 and determined that on October 19, 1994, the licensee had used a GM detector system at high count rates to measure the activity of hot particles on the right and left hand of a worker."... "Using the 80 microsecond resolving time and the licensee's measured count rate and stay time, the inspector calculated the skin dose to about 60 rems to the left and right hands each."

Amersham's Response:

We are currently performing the dose reassessments for the CAL. This matter will be fully addressed in our response to the CAL.

5/5 NRC Statement:

"It is also possible to obtain a better estimate of the attenuation of the beta radiation in the worker's shirt by using an Ir-192 source rather than a Cs-137 analog, as was done by the licensee."

Amersham's Response:

Cs-137 emits two betas: 1.17 Mev at 5.3 % yield and 0.5115 Mev at 94 % yield. Ir-192 emits three betas: 0.67 Mev at 46% yield, 0.536 Mev at 41 % yield and 0.24 Mev at 8 % yield. Effects of using Cs versus Ir on detector efficiency are negligible since the GM detector is relatively energy independent for beta response. For the purposes of calibrating the GM detector for betas, Cs-137 is acceptable.

Preliminary dose assessment did estimate beta attenuation using Cs-137 betas through the shirt material. We accept your point on attenuation. This approach was abandoned in the dose reassessment made on 12 April 1995 and replaced with a calculated estimate of attenuation based on Ir-192 beta energies.

6/1 NRC Statement:

"The source of the hot particles is mainly the small particles of Ir-192 that contaminates the sources received by the licensee from their suppliers."

Amersham's Response:

See response to 2/3.

6/2 NRC statement:

"The buildup of contamination inside the unloading cell has reached the point at which the cell itself has become a source of contamination."

Amersham's Response:

The unloading and loading cells were originally designed to minimize the potential for contamination from leaving the cells, but were not designed to assure full containment. All of the cells require the addition and removal of various access ports and are used for the

handling of contaminated items (including the bulk material). Records of air samples and wipes taken over the years show that the cells are effective in reducing the amount of contamination that leaves the cells. There did not appear to be a review by NRC during the special inspection of the operational modifications we have made over time to increase cell containment, or the routine procedures that are in place to minimize spread of contamination if brought out of cell. These routine procedures include floor masslins, closedown wipes etc., and are listed in Appendix 2.

6/3 NRC Statement:

"A review of the data provided by the licensee indicates that a likely mechanism of contamination is through the reuse of contaminated protective clothing."

Amersham's Response:

Our investigation related specifically to this incident supports the hypothesis that the suit was most probably contaminated through handling using a contaminated glove, based on the location of the contamination on the shirt.

However, based on our investigation we do not believe that the of reuse of clothing contributes to personnel contamination.

6/3 NRC Statement:

"There have been many cases, including the present one, in which workers were contaminated though they had not engaged in any work that involved handling contaminated items or working close to an ongoing operation that involved such items."

Amersham's Response:

The vast majority (90%) of contamination incidents can be tracked primarily to unloading and decontamination operations and secondarily to the loading operations. All three of these processes directly involve the handling of unencapsulated material which results in contaminated items. The cell operations are carried out in a contamination control area where the use of protective clothing is required for access.

The statement in the inspection report seems to imply that there

should be clean areas within the contamination control zone. The contamination control zone is the entire back area of the Radioisotope laboratory as indicated in the attached layout (Appendix 3). Although steps are taken to minimize and control contamination in this area, all activities performed within this area are assumed to involve handling of potentially contaminated items and surfaces, and the appropriate precautions are taken.

6/3 NRC Statement:

"The licensee stated that they adopted this practice to reduce radioactive waste."

Amersham's Response:

It was agreed during the telephone conversation that this statement would be deleted.

6/4 NRC Statement:

"There is no formal training on the use of protective clothing, especially on good practices to remove protective clothing when leaving contamination areas."

Amersham's Response:

Training has been provided to workers in Work Instruction S20, Contamination Control, prior to the reported overexposure. Prior to the implementation on this work instruction training was provided through the Radiation Safety Manual and specific training for new employees entering the contamination control area of the lab. There is also substantial on the job training for individuals working in the contamination control area as described in the response below.

6/4 NRC Statement:

"The licensee stated that they do not have formal training or procedures because of the small numbers of workers who frequent the contamination control area, estimated to be about 10 people."

Amersham's Response:

The employee misunderstood the inspector's question. There are formal procedures and training in place for all workers entering the contamination control area. In addition to the formal training there is on the job training for individuals working in the contamination control area. The individuals working in the contamination control area then go through a thorough qualification review by the Radiation Safety Officer and approval by our Radiation Protection and General and Safety Committee for the specific tasks that are performed in the contamination control area. This review and approval would cover the individuals ability to wear and handle protective clothing and contaminated items correctly to minimize the possibility of contamination.

6/5 NRC Statement:

"The hand shoe monitor primarily detects radioactive material found on the shoes, lower arm, and hand."

Amersham's Response:

A portal monitor, not a hand and shoe monitor, is used at the exit point of the contamination control area and detects radioactive material on the lower and upper leg, lower and upper arm, head and shoes. The portal is used as a preliminary screening not a clearing frisk. A full frisk is performed after the use of the portal monitor in order to be cleared from the area.

Appendix 1

Dose Reassessment

The following is a dose reassessment for the hot particle contamination occurrence from 24 March 95. This dose was reassessed after 12 April 95 based on the determination of additional information relative to the particle activity assessment. The following describes the activity reassessment which was performed and the revised dose assessment.

The activity assessment used in the 12 Apr 95 dose assessment was based on a unique geometry in the NaI well counter (contaminated wipes contained in a glove placed on top of the detector) and not in the geometry routinely calibrated for that counter. This value was then used as a baseline activity estimate and correlated to a survey meter reading to obtain an activity estimate of 7.5 uCi. Review of this well counter's response to changes in detector geometry showed a range of counter efficiencies based on particle location. The contaminated wipes contained in the glove were removed and all contaminated particulate isolated and placed in glass test tubes for counting in the calibrated detector geometry.

In addition, the counter was evaluated for dead time losses and the system dead time was determined using the two-source method detailed in Knoll (see Attachment 1). This evaluation determined the system dead time to equal 4 microsecs. This dead time was then factored into the activity assessments for the particles retrieved from the incident and read in the counter's calibrated geometry.

Consolidation of the particulate produced three test tubes for analysis. Activity was retrieved from the containment glove and two of the three kimwipes produced after particle flushing attempts through the shirt. The results of each test tube assay performed on 17 Apr 95 are shown below:

Sample	Net cpm	Dead Time Corrected cpm	Decay Corrected cpm	Activity in uCi
1	2,473,312.00	2,961,700.00	3,708,279.00	2.31
2	2,018,963.00	2,333,000.00	2,921,098.00	1.82
3	5,700,581.00	9,195,100.00	11,512,981.00	7.18
Totals:	10,192,205.00	14,489,800.00	18,142,358.00	11.32

After this consolidation, a comparison was made using the three particulate samples obtained and the TAN 2000 survey meter response. Assuming point source geometry and applicability of inverse square, the estimated intensity from an 11.32 uCi particle is calculated to be ~14 mR/hr. The particle measured prior to removal from the shirt using the TAN 2000 survey meter gave an intensity of 10-12 mR/hr. Based on this additional information, we believe that the entire particle was retrieved during the decontamination operation but that it had broken into three major portions located at varying depths in the glove which was used to contain them for counting purposes. This produced a lowered response from the counting equipment used to assess the activity incorporated into the 12 Apr 95 dose assessment.

Using the revised activity, the dose was reassessed and a skin dose of 73.729 rem was calculated to the skin a depth of 0.007 cm. The deep dose at 1 cm was recalculated at 83.138 mrem. The calculation sheet is attached along with copies of the calibration certificates for the well counter and survey instrument used in assessment calculations. The same equations for skin and deep dose were used for the 12 Apr 95 and this dose assessment. These values will be added to the employee's exposure records to document this hot particle exposure.

ATTACHMENT 1

TWO SOURCE METHOD OF DEAD TIME CALCULATION FROM KNOLL

"RADIATION DETECTION AND MEASUREMENT"
GLENN F. KNOLL, 1979

rates on the opposite side of the maximum. Mistakes in the interpretation of nuclear counting data from paralysable systems have occurred in the past by overlooking the fact that there are always two possible true interaction rates corresponding to a given observed rate. As shown in Fig. 3-8, the observed rate m_1 can correspond to either true rates n_1 or n_2. The ambiguity can be resolved only by changing the true rate in a known direction while observing whether the observed rate increases or decreases.

For low rates ($n \ll 1/\tau$) the following approximations can be written:

Nonparalysable: $$m = \frac{n}{1+n\tau} \cong n(1-n\tau) \tag{3-17}$$

Paralysable: $$m = ne^{-n\tau} \cong n(1-n\tau) \tag{3-18}$$

Thus the two models lead to identical results in the limit of small dead time losses.

B. Methods of Dead Time Measurement

In order to make dead time corrections using either model, prior knowledge of the dead time τ is required. Sometimes this dead time can be associated with a known limiting property of the counting system (e.g., a fixed resolving time of an electronic circuit). More often, the dead time will not be known or may vary with operating conditions and must therefore be measured directly. Common measurement techniques are based on the fact that the observed rate varies nonlinearly with the true rate. Therefore, by assuming that one of the specific models is applicable, and by measuring the observed rate for at least two different true rates which differ by a known ratio, the dead time can be calculated.

The common example is the *two-source method.* The method is based on observing the counting rate from two sources individually and in combination. Because the counting losses are nonlinear, the observed rate due to the combined sources will be less than the sum of the rates due to the two sources counted individually, and the dead time can be calculated from the discrepancy.

To illustrate the method, let n_1, n_2, and n_{12} be the true counting rates (sample plus background) with source 1, source 2, and the combined sources, respectively, in place. Let m_1, m_2, and m_{12} represent the corresponding observed rates. Also, let n_b and m_b be the true and measured background rates with both sources removed. Then

$$\begin{aligned} n_{12} - n_b &= (n_1 - n_b) + (n_2 - n_b) \\ n_{12} + n_b &= n_1 + n_2 \end{aligned} \tag{3-19}$$

Now assuming the nonparalysable model (Eq. 3-13) and substituting:

$$\frac{m_{12}}{1-m_{12}\tau} + \frac{m_b}{1-m_b\tau} = \frac{m_1}{1-m_1\tau} + \frac{m_2}{1-m_2\tau} \tag{3-20}$$

Solving this equation explicitly for τ gives the following result:

$$\tau = \frac{X(1-\sqrt{1-Z})}{Y} \tag{3-21}$$

where

$$X \equiv m_1 m_2 - m_b m_{12}$$
$$Y \equiv m_1 m_2 (m_{12} + m_b) - m_b m_{12}(m_1 + m_2)$$
$$Z \equiv \frac{Y(m_1 + m_2 - m_{12} - m_b)}{X^2}$$

A number of approximations to this general solution are often recommended in textbooks. For example, in the case of zero background ($m_b = 0$)

$$\tau = \frac{m_1 m_2 - [m_1 m_2 (m_{12} - m_1)(m_{12} - m_2)]^{1/2}}{m_1 m_2 m_{12}} \tag{3-22}$$

Other simplifications of Eq. 3-21 have appeared which are based on various mathematical approximations. However, the use of any type of approximation should be discouraged because significant errors can be introduced under typical experimental conditions[9]. Because the two-source method involves a substantial amount of experimental time and effort, it is difficult to justify the use of any expression other than Eq. 3-21 in analyzing the results.

Because the method is essentially based on observing the difference between two nearly equal large numbers, careful measurements are required in order to get reliable values for the dead time. The measurement is usually carried out by counting source 1, placing source 2 nearby and measuring the combined rate, and then removing source 1 to measure the rate due to source 2 alone. During this operation, care must be exercised not to move the source already in place, and consideration must be given to the possibility that the presence of a second source will scatter radiation into the detector which would not ordinarily be counted from the first source alone. Best results are obtained by using sources active enough to result in a fractional dead time $m_{12}\tau$ of at least 20 percent.

A second method can be carried out if a short-lived radioisotope source is available.* In this case the departure of the observed counting rate from the known exponential decay of the source can be used to calculate the dead time. The technique, known as the *decaying source method*, is based on the known behavior of the true rate n:

$$n = n_0 e^{-\lambda t} + n_b \tag{3-23}$$

where n_0 is the true rate at the beginning of the measurement and λ is the decay constant of the particular isotope used for the measurement.

*For laboratories with access to neutron irradiation facilities, a convenient isotope is ^{116m}In (half-life of 54.0 minutes), which is readily produced by neutron absorption in an indium foil.

rates on the opposite side of the maximum. Mistakes in the interpretation of nuclear counting data from paralysable systems have occurred in the past by overlooking the fact that there are always two possible true interaction rates corresponding to a given observed rate. As shown in Fig. 3-8, the observed rate m_1 can correspond to either true rates n_1 or n_2. The ambiguity can be resolved only by changing the true rate in a known direction while observing whether the observed rate increases or decreases.

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The common example is the *two-source method*. The method is based on observing the counting rate from two sources individually and in combination. Because the counting losses are nonlinear, the observed rate due to the combined sources will be less than the sum of the rates due to the two sources counted individually, and the dead time can be calculated from the discrepancy.

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$$n = n_0 e^{-\lambda t} + n_b \tag{3-23}$$

where n_0 is the true rate at the beginning of the measurement and λ is the decay constant of the particular isotope used for the measurement.

*For laboratories with access to neutron irradiation facilities, a convenient isotope is ^{116m}In (half-life of 54.0 minutes), which is readily produced by neutron absorption in an indium foil.

ATTACHMENT 2

CALIBRATION INFORMATION FOR ORTEC 1079 WELL COUNTER
AND TAN 2000 SN 7202

survey meter calibration certificate

SENTINEL

Amersham Corporation
40 North Avenue
Burlington, MA 01803
tel (617) 272-2000

Make and Model No. Amersham TAN 2000 SN 7202

Calibration Date 2/6/95

meter range	mr/hr applied field	meter reading as received	meter reading after adjustment
x1	~~2.1~~ 2.0	—	2.0
x1	~~7.8~~ 8.0	—	8.3
x10	20	18	19
x10	80	78	85
x100	~~200~~ 200	170	170
x100	800	780	810

Calibration was performed with a cesium-137 source in a Amersham Model 773 Calibrator. The applied field was measured with a Radcal Corp Model 20x5-180 ion chamber whose response to cobalt-60 and cesium-137 radiations had been determined by a National Bureau of Standards-approved calibration laboratory, and whose sensitivity is monitored by reference to an NBS-calibrated cobalt-60 source. Applied field exposure rates are known with an uncertainty no greater than ± 2%.

For use as a radiography survey meter, Nuclear Regulatory Commission regulations (10CFR34.24) require that meters be recalibrated within three months.

Calibration performed for

Radio isotope Lab

Amersham Corporation

by Jack Okrent

Amersham QSA

SCALER CALIBRATION DATA SHEET

MODEL: ORTEC
SERIAL: 1079

DATE: 11-Mar-95

	Ir-192	Co-60	Cs-137	U-238	Yb-169	Gd-153
ACTIVITY in uCi	N\A	0.003248	0.078246	0.25	N/A	0.000014
COUNT RATE	135460	3653	55988	0		47
	135801	3523	56164	0		61
	135370	3616	56515	0		60
	135398	3555	56626	0		52
	135705	3563	56311	235000		45
AVERAGE COUNT RATE	135547 cpm	3582 cpm	56321 cpm	47000 cpm	N/A	53 cpm
EFFICIENCY	70.0 %	49.7 %	32.4 %	8.5 %	173.7 %	168.3 %
CALIBRATION FACTOR in uCi/cpm	6.43E-07	9.07E-07	1.39E-06	5.32E-06	2.59E-07	2.68E-07
0.001 uCi EQUIVALENT to	1555 cpm	1103 cpm	720 cpm	188 cpm	3855 cp	3737 cpm
AIR SAMPLE CALIBRATION FACTOR in uCi.* hr / cpm * ml	1.07E-12	1.51E-12				4.46E-03
THRESHOLD CONCENTRATION	8.93 %					

Based upon Previous Calibration

DONE: 11-Mar-95
DUE: 10-Jun-95

TECHNICIAN: [signature]

ATTACHMENT 3

CALCULATION SHEET FOR DOSE REASSESSMENT - 24 MAR 95 EXPOSURE

TECHNICIAN:
LOCATION: Middle of Back
DATE: 24 Mar 95

Variables			DOSE1 CALCS.	
c =	1.600E−06	rad−g/MeV	2.0756210	
A =	1.330E+08	B/uCi−hr	0.0747919	
L =	5.640E−01	cm	0.3726063	
Emax1 =	6.700E−01	MeV	−0.1319766	
Y1 =	4.600E−01			
Eave1 =	2.200E−01	MeV	1.845	Rad/uCi−hr
Sm1 =	4.240E+00	Mev−cm2/g		
v1 =	3.470E+01	cm2/g		
R1 =	2.445E−01	g/cm2		
Theta =	88.2	degrees		
R1' calculated =	5.400E−01	g/cm2		
R1' assigned =	2.445E−01	g/cm2	(smaller of R1 and R1')	
H =	1.815E−02	g/cm2		
x1 =	5.000E−02	cm		
rhox1 =	2.230E−01	g/cm3		
x1 * rhox1 =	1.115E−02	g/cm2		
Aw1 =	9.300E−01			
x2 =	0.000E+00	cm		
rhox2 =	0.000E+00	g/cm3		
x2 * rhox2 =	0.000E+00	g/cm2		
Aw2 =	0.000E+00			
Aeff =	9.570E−01			
Aeff * H =	1.737E−02	g/cm2		
Aeff * R1' =	2.340E−01	g/cm2		
v1H =	6.027E−01			
v1R1' =	8.119E+00			
v1R =	8.484E+00			
E1(v1H) =	4.520E−01	(only good for 1<(vH)<110 or vH=1)		
E1(v1R1') =	3.298E−05	(only good for 1<(vR1')<110 or vR1'=1)		
k1 =	1.384E+00			

Variables			DOSE2 CALCS	
c =	1.600E−06	rad−g/MeV	2.1765552	
A =	1.330E+08	B/uCi−hr	0.0581224	
L =	5.640E−01	cm	0.3251005	
Emax2 =	5.360E−01	MeV	−0.1207983	
Y2 =	4.100E−01			
Eave2 =	1.730E−01	MeV	1.309	Rad/uCi−hr
Sm2 =	4.960E+00	Mev−cm2/g		
v2 =	4.608E+01	cm2/g		
R2 =	1.800E−01	g/cm2		
Theta =	88.2	degrees		
R2' calculated =	5.400E−01	g/cm2		
R2' assigned =	1.800E−01	g/cm2	(smaller of R2 and R2')	
H =	1.815E−02	g/cm2		
x1 =	5.000E−02	cm		
rhox1 =	2.230E−01	g/cm3		
x1 * rhox1 =	1.115E−02	g/cm2		
Aw1 =	9.300E−01			
x2 =	0.000E+00	cm		
rhox2 =	0.000E+00	g/cm3		
x2 * rhox2 =	0.000E+00	g/cm2		
Aw2 =	0.000E+00			
Aeff =	9.570E−01			
Aeff * H =	1.737E−02	g/cm2		
Aeff * R2' =	1.723E−01	g/cm2		
v2H =	8.351E−01			
v2R2' =	8.282E+00			
v2R =	8.654E+00			
E1(v2H) =	2.917E−01	(only good for 1<(vH)<110 or vH=1)		
E1(v2R2') =	2.754E−05	(only good for 1<(vR2')<110 or vR2'=1)		
k2 =	1.180E+00			

Variables			DOSE3 CALCS	
c =	1.600E−06	rad−g/MeV	0.8797143	
A =	1.330E+08	B/uCi−hr	0.0072665	
L =	5.640E−01	cm	0.0801621	
Emax3 =	2.400E−01	MeV	−0.0453944	
Y3 =	8.000E−02			
Eave3 =	7.300E−02	MeV	0.036	Rad/uCi−hr
Sm3 =	7.980E+00	Mev−cm2/g		
v3 =	1.642E+02	cm2/g		
R3 =	5.600E−02	g/cm2		
Theta =	88.2	degrees		
R3' calculated =	5.400E−01	g/cm2		
R3' assigned =	5.600E−02	g/cm2	(smaller of R3 and R3')	
H =	1.815E−02	g/cm2		
x1 =	5.000E−02	cm		
rhox1 =	2.230E−01	g/cm3		
x1 * rhox1 =	1.115E−02	g/cm2		
Aw1 =	9.300E−01			
x2 =	0.000E+00	cm		
rhox2 =	0.000E+00	g/cm3		
x2 * rhox2 =	0.000E+00	g/cm2		
Aw2 =	0.000E+00			
Aeff =	9.570E−01			
Aeff * H =	1.737E−02	g/cm2		
Aeff * R3' =	5.359E−02	g/cm2		
v3H =	2.852E+00			
v3R3' =	8.799E+00			
v3R =	9.194E+00			
E1(v3H) =	1.577E−02	(only good for 1<(vH)<110 or vH=1)		
E1(v3R3') =	1.554E−05	(only good for 1<(vR3')<110 or vR3'=1)		
k3 =	9.486E−01			

DOSE FACTOR =	3.190	Rad/uCi−hr
ACTIVITY =	11.320	uCi
EXPOSURE TIME =	2	hrs
BETA SKIN DOSE =	72.222	Rad

DOSE FACTOR =	66.6	mRad/uCi−hr
ACTIVITY =	11.320	uCi
EXPOSURE TIME =	2	hrs
GAMMA SKIN DOSE =	1.507	Rad

TOTAL SKIN DOSE =	73.729	Rad

Variables			DOSE1 CALCS.	
Gamma Constant =	4.606	mrad−cm2/uCi−hr	9.94514037	
R =	5.640E−01	cm	66.5520044	Dose Factor
H =	7.000E−03	cm		
x =	5.000E−02	cm (thickness between HP and skin)		
d =	5.700E−02	cm		

DOSE FACTOR =	3.7	mRad/uCi−hr
ACTIVITY =	11.32	uCi
EXPOSURE TIME =	2	hrs
GAMMA DOSE (1 cm) =	83.138	mRad

Variables			DOSE1 CALCS.	
Gamma Constant =	4.606	mrad−cm2/uCi−hr	1.13513102	
R =	5.640E−01	cm	3.87219445	Dose Factor
H =	1.000E+00	cm		
x =	5.000E−02	cm (thickness between HP and skin)		
d =	1.050E+00	cm		

*SEE ATTACHMENTS FOR SUPPORTIVE INFORMATION ON INPUT VALUES.

FORM: 032495-1.wk1

$$DR = \sum_i \frac{\gamma_i C A Sm_i}{2\pi L^2}\left[E_1(\nu_i H) - E_1(\nu_i R_i') + K_i\left[\frac{1.16}{\nu_i R_i}\left(e^{-\nu_i H} - e^{-\nu_i R_i'}\right) + \frac{30.67}{(\nu_i R_i)^2}\left(e^{-\nu_i H}(\nu_i H + 1) - \cdots\right.\right.\right.$$

$$\cdots e^{\nu_i R_i'}(\nu_i R_i' + 1)\Big) + \frac{41.8}{(\nu_i R_i)^3}\Big((\nu_i R_i')^2 e^{-\nu_i R_i'} - (\nu_i H)^2 e^{-\nu_i H} + 2e^{-\nu_i R_i'}(\nu_i R_i' + 1) - \cdots$$

$$\left.\left.\left. \cdots 2e^{-\nu_i H}(\nu_i H + 1)\right]\right]$$

BASIC BETA DOSE EQUATION ↑

$$Sm_i = 10.1 e^{-2.8 E_{max}} + 2.9 e^{-0.11 E_{max}}$$

$$\nu_i = 18.6 (E_{max} - 0.036)^{-1.37}$$

$$R_i = 0.412 E_{max}(1.265 - 0.0954 \ln E_{max})$$

$$K_i = \frac{\left(\frac{E_{max}^{ave;}}{Sm_i} - \frac{1}{\nu_i}\right)\nu_i}{\left[\frac{1.16}{\nu_i R_i} + \frac{61.34}{(\nu_i R_i)^2} - \frac{250.8}{(\nu_i R_i)^3}\right]}$$

GAMMA DOSE EQUATION ↓

$$DR = \frac{2 A \Gamma \ln\left(\frac{\sqrt{H^2 + R^2}}{H}\right)}{R^2}$$

Appendix 2

Routine Procedures

PROCEDURES/ACTIONS FOR CONTAMINATION CONTROL

Routine actions and requirements:

Contamination control:

Daily

-Daily wipes before and after operations in contamination control area, if greater than 250 dpm, area is rewiped until clean.
-Masslinns (area mops) are performed at beginning and end of day in the contamination control area and the and also at the conclusion of a decontamination procedure, if greater than 700 dpm then a rewipe is taken until clean.
-Masslinns (area mops) are performed at beginning and end of the day in the hallways of lab, if greater than 250 dpm, the area is rewiped to acceptable levels and RSO is notified for possible additional actions.
-Sticky mats at exit areas of contamination control area and lab are replaced twice a day. Replacement of sticky mat ensures continued sticky surface during its use, ie dirt buildup in minimized. If contamination levels exceed 1000 dpm RSO is notified for possible additional actions.
-Daily air samples taken during operations and overnight, baseline shows no airborne contamination greater than 1 E-12 uCi/ml. Unusual results are investigated.

Weekly

-Loading cells decontaminated weekly to keep contaminaiton levels low. When radiation levels get above 30 mR/hr in cell, actions must be taken to reduce levels to below 30 mR/hr.
-Wipes taken of cutting cell at start of week, if above 150 dpm, RSO notified.
-Masslinns taken in the exposure rooms of lab, if greater than 250 dpm, area is rewiped and RSO notified.

Monthly

-Monthly surveys performed of entire laboratory and unrestricted areas in facility. No contamination found in unrestricted areas. Results of wipes in the restricted area are normally below acceptable level, more than 99% of wipes are clean in the restricted area. If exceed level, area is promptly decontaminated till clean.

Semi annual:
-Whole Body counts performed with no significant results.

Portal Monitor

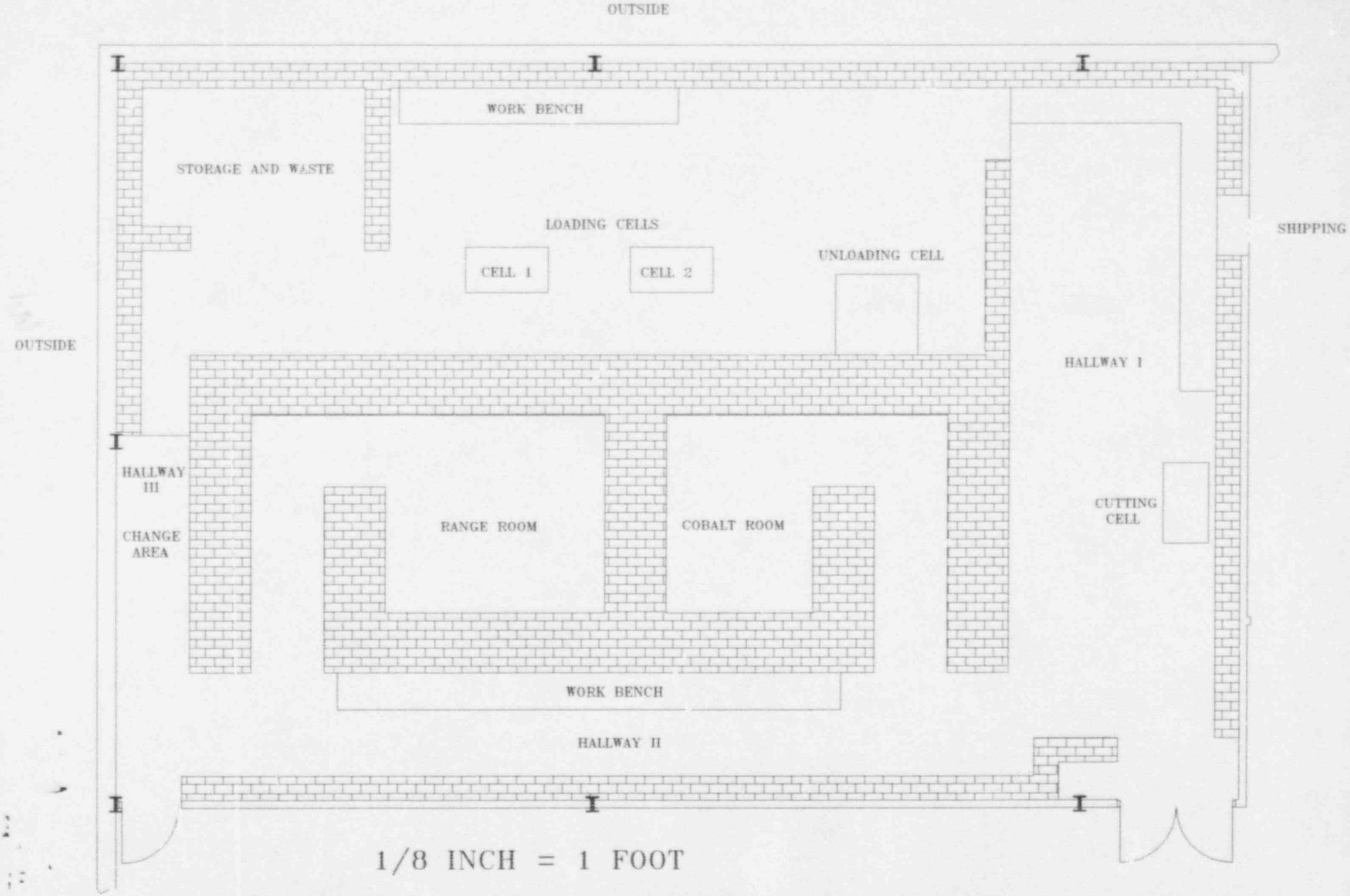
-All personnel exits from contamination control area must pass through portal monitor.

Frisking/Protective clothing removal

-Protective clothing removal performed in accordance with established procedures in WI S-20.
-All personnel exits from contamination control area require frisking using a calibrated contamination monitor in accordance with WI S-20, anything above background is reported/decontaminated in accordance with WI R-33.

Appendix 3

Radioisotope Laboratory Layout


OUTSIDE
WORK BENCH
STORAGE AND WASTE
LOADING CELLS
CELL 1
CELL 2
UNLOADING CELL
SHIPPING
OUTSIDE
HALLWAY I
HALLWAY III
CHANGE AREA
RANGE ROOM
COBALT ROOM
CUTTING CELL
WORK BENCH
HALLWAY II
1/8 INCH = 1 FOOT