APPLYING ALARA PRINCIPLES IN THE DESIGN OF NEW RADIOLOGICAL FACILITIES

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***Abstract*--The application of ALARA (As Low As Reasonably Achievable) principles to the design of new radiological facilities at Argonne National Laboratory provides a consistent radiation safety basis for future facility operations. This paper discusses the criteria for controlling radiation exposure and the techniques applied to meet those criteria for two new facilities. Argonne is a Department of Energy (DOE) laboratory, and the criteria are specified in the DOE Rule found at 10 CFR 835. The worst case radionuclides and their source strengths are chosen. Local shielding is specified to reduce dose rates to less than 50 µSv hr^{-1}at 30 cm from the shielding, thus avoiding the creation of a radiation area. Version 6 of the Los Alamos National Laboratory radiation transport code MCNP is then used to calculate the dose rates elsewhere. Based on the results of the calculations, design modifications are made to meet the design objectives criteria. This work was supported by the U.S. Department of Energy, Office of Science, under Contract No. DE-AC02-06CH11347.**

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INTRODUCTION

Argonne National Laboratory (Argonne) is a Department of Energy (DOE) funded multi-purpose research laboratory operated by the University of Chicago. Argonne has approximately 3400 employees and about 6700 facility users (pre-pandemic). There is a radiological safety organization headed by the Radiation Safety Officer (RSO) and a Facility Design and Modifications Committee with members from divisions having radiation workers. The Committee is chaired by a Laboratory ALARA (as low as reasonably achievable) Coordinator and reviews radiological projects such as the ones discussed in this paper.

Two new radiological facilities are being added to facilitate materials research at Argonne National Laboratory: the Radiation Laboratory (Rad Lab) on the third floor of the Materials Design Laboratory (MDL) and the Activated Materials Laboratory (AML) adjacent to the new High-Energy X-ray Microscope (HEXM) beam line at the Advanced Photon Source (APS).

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These facilities use fume hoods and glove boxes to handle radioactive sources. Design of the Rad Lab improves capabilities for studying actinides (transuranic materials) and design of AML permits samples with higher levels of radioactivity to be examined using synchrotron radiation from the APS. In determining the design specifications for each new facility, worst case radionuclides and their source strengths are chosen. The designs utilize protection principles based on time, distance, and shielding. Occupancy factors are an important consideration. The radiation sources are considered point sources, so exposures without any shielding vary inversely with the square of the distance. Local shielding, a cost-effective solution for point sources, is specified to reduce dose rates from the fronts of fume hoods and glove boxes to less than 50 µSv hr^{-1} at 30 cm (the DOE threshold for designation as a radiation area). Version 6 of the Los Alamos National Laboratory Monte Carlo radiation transport computer code MCNP [MCNP6 2013] is then used to calculate the dose rates elsewhere. Design modifications are made to meet the Department of Energy design objectives [DOE 2007]. The calculations and resulting modifications are discussed, including the impacts of penetrations for utilities. The design of the MDL Rad Lab is presented first, followed by the design of AML. Then the ALARA aspects are discussed and the conclusions summarized.

MDL RADIATION LABORATORY DESIGN

The Materials Design Laboratory (MDL) is a new facility completed at Argonne in 2020. The MDL design specifies 15 cm thick concrete floors. The distance between floors is 488 cm. The glove boxes and fume hoods specified will support local shielding weighing 976 kg/m^2. Use of ungrouted concrete masonry units (CMU's, Fig. 1) with large voids is specified between the Radiation Laboratory (Rad Lab) and the offices on the Rad Lab floor except for grouted CMU's for the Rad Storage Room, Electrical Closet, and where office rearrangements can reduce the distance between source and office worker to 450 cm or less. Office occupants are not required to wear dosimetry in the offices and are considered members of the public for the ALARA design. The annual radiation doses in offices are calculated using the Monte Carlo computer code MCNP6, based on worst case radionuclides. The program traces each photon and neutron, taking account of initial and secondary particle interactions and energy depositions for millions of initial emissions. Complex geometries are modeled accurately. The chosen worst case radionuclides were a photon emitter, ^{60}Co, with a maximum strength of 37 MBq and a spontaneous neutron emitter, ^{248}Cm, with a maximum amount of 100 mg which corresponds to a strength of 16 MBq.

The unshielded dose rate at 30 cm for ^{60}Co is 128 µSv hr^{-1}. The calculated dose rates for ^{60}Co with and without lead shielding is given in Table 1. For ^{60}Co, with a maximum strength of 37 MBq, a lead shield 2.54 cm thick will reduce the dose rate at 30 cm to 39 µSv, avoiding the DOE designation as a radiation area. Annual calculated doses at 488 cm from a ^{60}Co point source with unshielded dose rates of 50 µSv hr^{-1} at 30 cm based on 2,000 hours occupancy are found in Table 2.

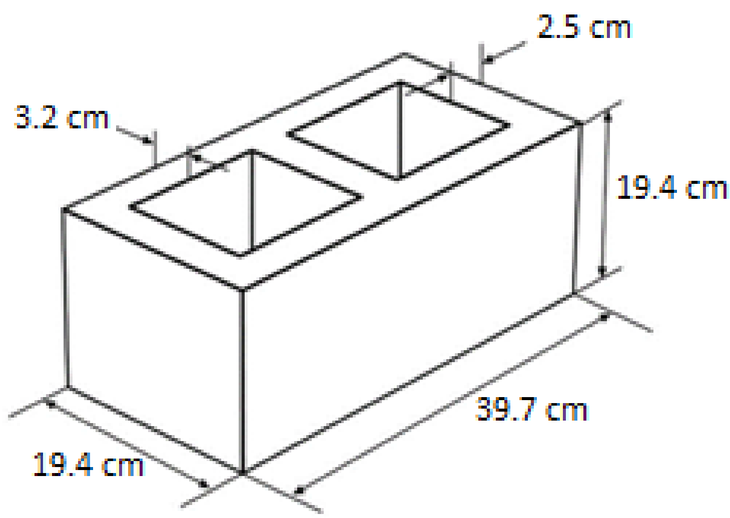

Fig. 1. Concrete Masonry Unit

Table 1. Calculated dose rates with and without lead shielding for 37 MBq ^{60}Co source

Lead shielding Thickness (cm)	Dose rate ($\mu Sv\ hr^{-1}$) at different distances		
	30 cm	100 cm	488 cm
None	128	18	1.5×10^{-1}
2.54	39	3.6	3.9×10^{-2}
5.08	9.7	0.88	8.8×10^{-3}
7.62	2.3	0.20	2.0×10^{-3}
10.16	0.51	4.6×10^{-2}	4.9×10^{-4}
12.7	0.10	8.7×10^{-3}	1.3×10^{-4}
15.24	0.027	2.3×10^{-3}	8.5×10^{-5}

Table 2. Annual calculated doses at 488 cm from ^{60}Co point sources with locally shielded dose rates of 50 μSv hr^{-1} at 30 cm based on 2,000 hours occupancy

Added Shielding material	Annual dose at 488 cm from point source (mSv)
None	0.296
Ungrouted CMU	0.160
Grouted CMU	0.049
15.2 cm thick concrete	0.065

The unshielded dose rate at 30 cm for the worst case 100 mg ^{248}Cm source is 617 μSv hr^{-1}. The calculated annual dose for ^{248}Cm as a function of source strength is given in Table 3 using borated polyethylene to reduce the dose rate to 50 μSv hr^{-1} at 30 cm. Note that the maximum annual dose at 488 cm occurs when no borated polyethylene is used (no neutron moderator). The amount of borated polyethylene necessary does not scale linearly with source strength as a result of changes in the neutron spectrum from neutron moderation (Fig. 2). The calculated worst case ^{248}Cm annual dose rates at 488 cm for different construction materials are given in Table 4.

Table 3. ^{248}Cm source strength producing a dose rate of 50 μSv hr^{-1} at 30 cm

^{248}Cm source strength (mg)	^{248}Cm source strength (MBq)	Thickness of borated polyethylene (cm)	Annual dose through 15.2 cm of concrete at 488 cm from source (mSv)
8	1.24	0	0.19
17	2.64	5.08	0.11
44	6.81	10.2	0.09
108	16.7	15.2	0.08

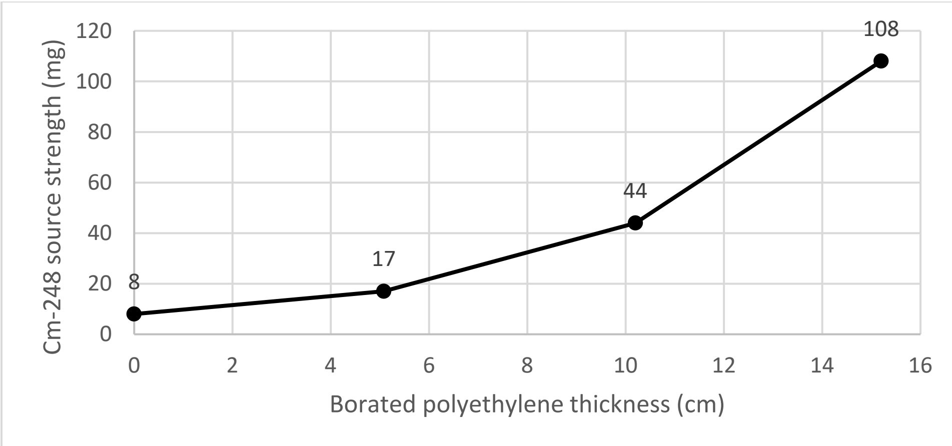

Fig. 2. ^{248}Cm source strength in mg vs. polyethylene thickness in centimeters

Table 4. Highest annual calculated doses at 488 cm from worst case 8 mg ^{248}Cm point source (from Table 3) with locally shielded dose rates of 50 µSv hr^{-1} at 30 cm based on 2,000 hours occupancy

Added Shielding material	Annual dose at 488 cm from point source (mSv)
None	0.47
Ungrouted CMU	0.33
Grouted CMU	0.2
15.2 cm thick concrete	0.19

The DOE Rule (DOE 2007) found at 10 CFR 835.1002 specifies design objectives to be adopted during the design of new facilities for controlling personnel radiation exposure. The primary objective is to keep exposure levels below 20% of the applicable standards in 10 CFR 835.202. See Table 5.

Table 5. DOE criteria used in the design

DOE criterion description	Criterion	10 CFR reference	ALARA 20% criterion	10 CFR reference
Worker whole body dose limit	50 mSv/y	835.202	10 mSv/y	835.1002
Worker average dose rate assuming 2,000 hr/y	25 µSv/hr	835.202	5 µSv/hr	835.1002
Radiation area threshold dose rate at 30 cm from source or shielding (radiation area threshold)	50 µSv/hr	835.2		
Worker extremity dose limit	0.5 Sv/y	835.202	0.1 Sv/y	835.1002

Member of public dose limit	1 mSv/y	835.208	0.2 mSv/y	835.1002

For a radiation worker 20% of the standard corresponds to an average of 5 µSv hr^{-1} for a 2,000 hour work year. For a member of the public the DOE design objective corresponds to 0.2 mSv in a calendar year. The DOE design objective for the radiation worker is to keep the individual dose to a radiation worker below 10 mSv y^{-1} or an average of 5 µSv hr^{-1}. The shielding inside the fume hood or glove box must be sufficient to reduce the dose rate to meet the design objective. This requires the addition of shielding between the source and the radiation worker and for this design is conservatively based on 2,000 hours occupancy. Based on the calculations in Table 1, 7.6 cm of lead reduces the dose rate to 2.25 µSv hr^{-1} at 30 cm from the 37 MBq ^{60}Co source. The fume hood or glove box is designed for a load of 976 kg/m^2 and will support 7.6 cm of lead shielding. This meets the DOE design objectives criterion of an average of 5 µSv hr^{-1}. For the MDL the source location is assumed to be at the center of the hood or glove box and, therefore, the distance from source to worker is greater than 30 cm. During operations the shielding thickness can be optimized based on the source location. Actinides are primarily alpha-particle emitters which present an internal dose hazard. The Rad Lab replaces an actinide chemistry research facility. Based on years of experience with actinides at that facility, the extremity dose can be managed without the use of manipulators. See Table 5 for the extremity dose criteria.

Applying DOE ALARA Criteria

The occupancy factors for MDL based on Argonne RSO guidance and projected operations, are given in Table 6. Based on 2,000 hours occupancy for members of the general public, the annual maximum doses in the Rad Lab offices and in the offices on the floor below need to be kept below 0.2 mSv (Table 5). Based on calculated annual dose rates, there are only a few places where that criterion is not met. Modifications to meet all the criteria are discussed below.

Table 6. MDL occupancy factors based on RSO guidance and projected operations

Location	Occupancy factor	Hours per year
Rad Lab offices	1	2,000
Offices on floor below	1	2,000
Maintenance floor above	0.5	1,000
Rad Lab restrooms	0.2	400
Corridors	0.2	400
Electrical Closet	0.06	120

Prescription for local shielding around the neutron source:

a. Up to 25 µSv hr^{-1} unshielded at 30 cm (4 mg of ^{248}Cm), no borated polyethylene shielding is needed.
b. Between 25 µSv hr^{-1} and 50 µSv hr^{-1} at 30 cm unshielded, add 5.08 cm of borated polyethylene to ensure the design criterion is met.
c. Increase the thickness of borated polyethylene to keep the 30 cm dose rate at 50 µSv hr^{-1} as the source strength is increased.

Facility Modification for Worst Case Furniture Arrangement

By keeping all dose rates in the Rad Lab facility below the threshold defined for a radiation area, 50 μSv hr^{-1} at 30 cm from the source or from any surface that the radiation penetrates, the design criterion of an annual dose less than 0.2 mSv from sources in the Rad Lab facility can be met for an individual in an office on the Rad Lab floor and for an individual on the floor below the Rad Lab. The 50% design configuration for the Rad Lab floor is shown in Fig. 3. The 50% design configurations means design is at 50% or halfway to the final design, at this point if needed there was still time to make design changes. Note the minimum distances (571, 574, and 612 cm) shown from fume hoods and glove boxes to desk chairs in the offices. It is possible to rearrange the furniture in the offices to place the desk chair much closer to the source. Such a configuration is shown in Fig. 4. The distance from the source to the individual office worker is about 366 cm in such an arrangement. The dose is higher by about 2.5 times in that case which could exceed the threshold of 0.5 mSv y^{-1} for mandatory individual monitoring, assuming the maximum strength source is in the closest hood or glove box for the entire year (2,000 hours).[2] The office would have to be designated as a controlled area. A facility modification is needed to avoid that designation and meet the design criterion. Using grouted CMU for construction of a wall between the source and corner offices reduces the dose to below 0.2 mSv y^{-1} when that is the case. Based on these calculations a decision was made to add grout. The added grout also is necessary for meeting the design criterion for the corridor. The occupancy factor for the corridor is 0.2 (400 hours per year, Table 6). For the design calculation, the receptor is located at the center of the corridor.

[2] Processing samples moves the source from one hood or glove box to another; however some samples could remain in a given hood or glove box for an extended period of time. Thus, using 2,000 hours is a very conservative, defendable choice for design.

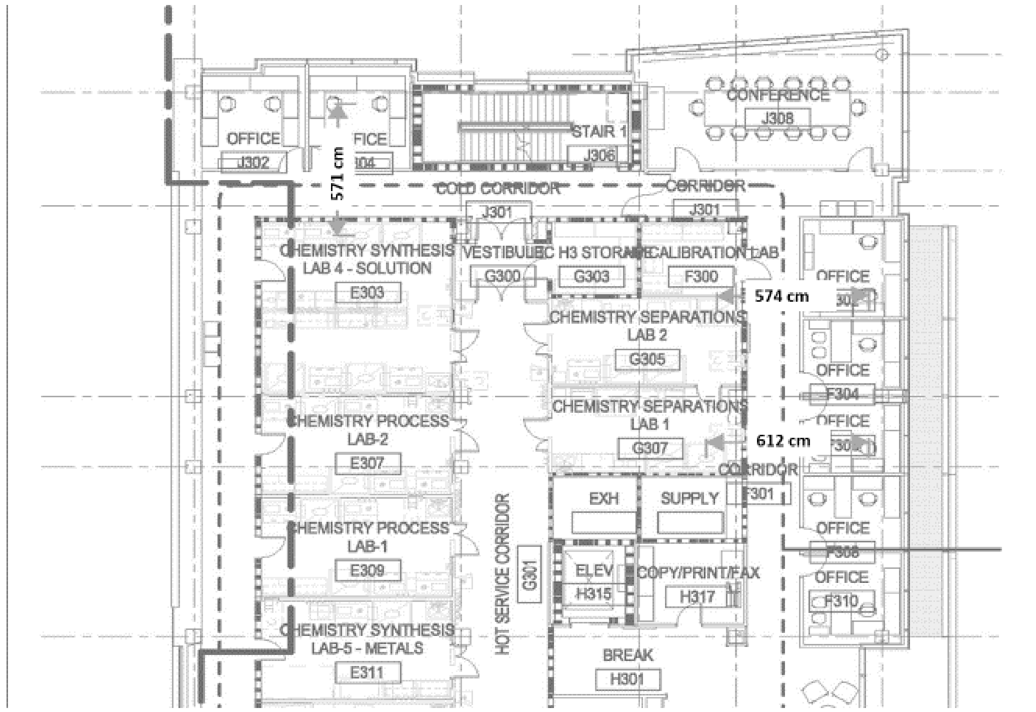

Fig. 3. Minimum distances from MDL Radiation Laboratory fume hoods and glove boxes to desk chairs in the offices– 50% design drawing (50 % of the way toward 100% or final design, i.e, still time to make design changes)

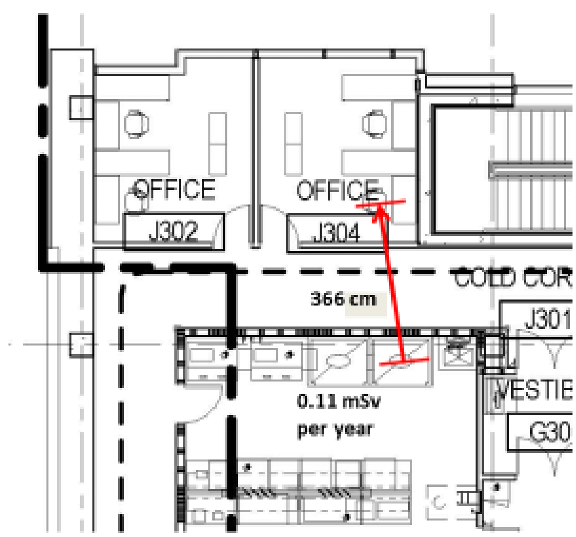

Fig. 4. Worst case arrangement of desk chairs in the MDL offices

Area and Trench Drains

The area and trench drains are located in the interior corridor and are sized to accommodate fire suppression sprinkler system water flow upon release. The area drains are 36.6 cm in diameter. The trench drains are 45.7 cm wide × 152 cm long. The radiation source is located 100 cm above the Rad Lab floor. The nearest edge of a trench drain is 100 cm laterally from the radiation source. The drains penetrate the 15.2 cm thick concrete floor. MCNP6 calculations were made to determine the impact of the holes through the floor on personnel (receptors) on the floor below the Rad Lab. The receptors are on a horizontal line which is 488 cm vertically below the source elevation, 100 cm above the Rad Lab floor, and 150 cm from the center of the drain. The results for the trench drain are given in Figure 5. The maximum increase in dose rate from ^{60}Co is 60%, and there is no increase in dose rate from ^{248}Cm. Note in Figure 5 that the maximum dose rate is at a lateral distance corresponding to diagonal line-of-sight through the open hole through the concrete. The results for the area drains are given in Figure 6 for a 37 MBq ^{60}Co source and for a 100 mg ^{248}Cm source. The maximum increase in dose rate from ^{60}Co is 12%, and there is no increase in dose rate from ^{248}Cm. Thus, the dose remains below 0.2 mSv y^{-1} for ^{60}Co and for ^{248}Cm. See Tables 2 & 4 for calculated doses without penetrations.

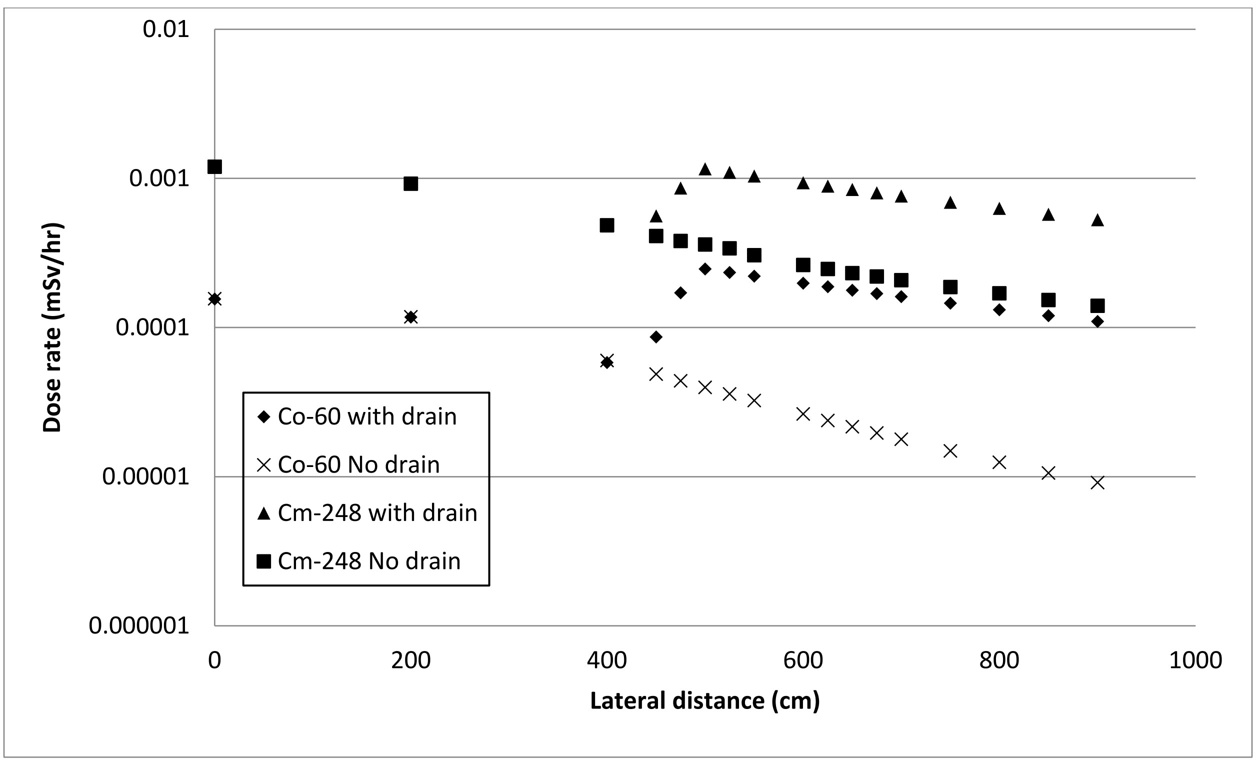

Fig. 5. Receptor dose rate below trench drain without local shielding to reduce the dose rate at 30 cm to 0.05 mSv/hr

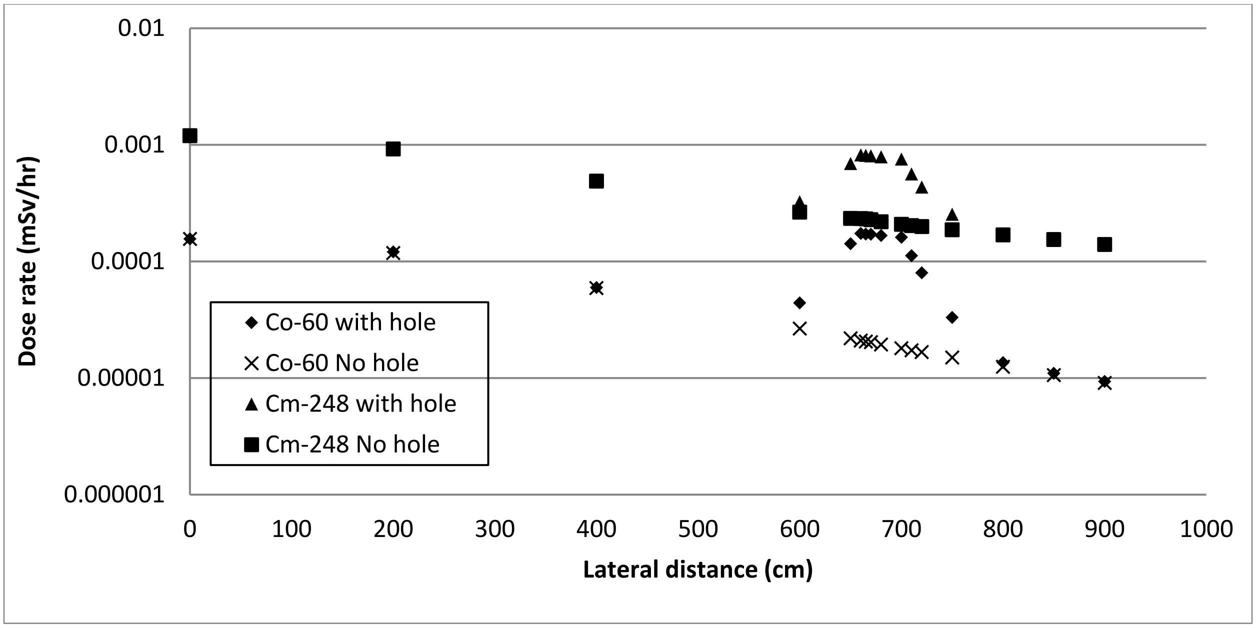

Fig. 6. Receptor dose rate below area drain without local shielding to reduce the dose rate at 30 cm to 0.05 mSv/hr

Rad Storage Room

The dose rate is kept below 50 µSv hr^{-1} at 30 cm from the local shielding for sources stored in the Rad Storage Room (Fig. 7) in order to meet the ALARA design criterion. This includes areas below the source as well as in other directions. Grout is added to CMU in the walls of the Rad Storage Room and the thickness of the concrete is increased by 7.62 cm in the floor and ceiling to permit storage of multiple sources. The door to the Rad Storage Room is shielded with 5.08 cm of borated polyethylene closer to the source followed by 2.54 cm of lead to keep the annual dose to users of the restrooms across the interior corridor (warm corridor) below 0.2 mSv. Placing the lead after the polyethylene attenuates the neutron capture gamma rays produced in the polyethylene. Storing sources in the Rad Storage Room when not in use helps ensure an average of 5 µSv hr^{-1} at 30 cm from the source or from any surface that the radiation penetrates when a source is in use.

Adjacent to the Rad Storage Room is the Electrical Closet. This area is normally not occupied; however there might be times when repairs need to be made on electrical equipment in that room. The wall between the Rad Storage Room and the Electrical Closet is grouted CMU. A decision was made to grout the side walls of the Electrical Closet as well to reduce the dose to an electrical worker from sources in the hoods and glove boxes in rooms adjacent to the Electrical Closet. Calculations made show that the dose to an electrical worker spending 120 hours on electrical repairs at 30 cm from the wall would be less than 0.2 mSv.

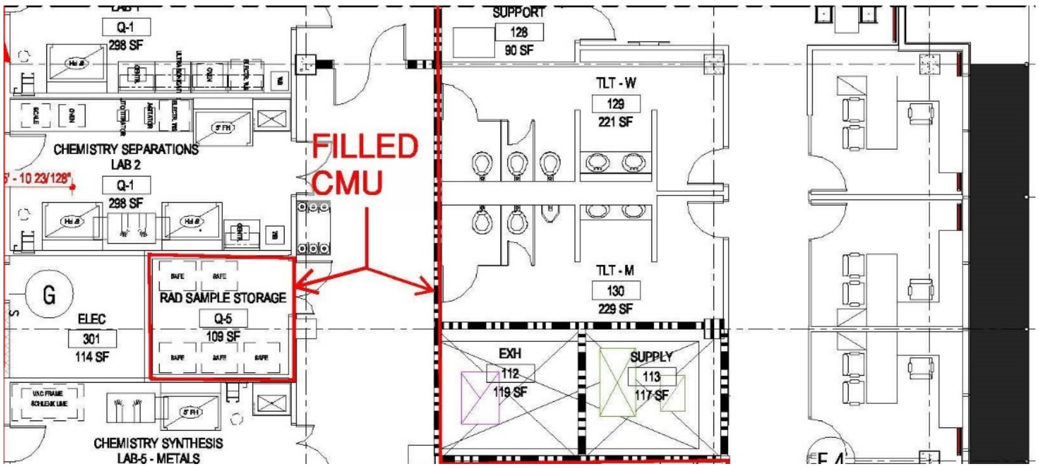

Fig. 7. MDL Rad Lab 50% design plan view showing the Electrical Closet, Rad Storage Room, and restrooms with grouted CMU. Note: Grouted CMU was specified later for the walls of the Electrical Closet adjacent to hoods and glove boxes.

Rad Lab Ceiling Penetrations

Worst case - two adjacent 33 cm (13”) diameter ceiling penetrations: The chosen source location was in a hood 100 cm above the Rad Lab floor, 66 cm from centerline of the closer 33 cm diameter hole. MCNP6 dose rate calculations were made 100 cm above the maintenance floor or 488 cm vertically above the source. The annual dose for 1,000 hours occupancy at 30 cm from the outside of the exhaust duct is 0.21 mSv for a ^{60}Co source and 0.30 mSv for a ^{248}Cm source. Source is assumed to be in the nearest hood or glove box for the entire 1,000 hours of occupancy. The exhaust duct prevents a worker from occupying the space directly above the 33 cm diameter hole. Since there are no filters to replace at this location, there is no planned need to spend any time at this location. At 30 cm from a **filter housing** for 1,000 hours of occupancy the worst case annual doses are calculated to be 0.04 mSv y^{-1} for a ^{60}Co source and 0.16 mSv y^{-1} for a ^{248}Cm source.

AML LABORATORY DESIGN

In order to comply with the ALARA design criteria (Table 5) a set of bounding conditions are established for the Activated Materials Laboratory (AML) at the Advanced Photon Source (APS). The worst-case radionuclide is chosen to be ^{60}Co and the dose rate at 30 cm from an unshielded ^{60}Co source is limited to 1 mSv hr^{-1} at 30 cm. This corresponds to an unshielded source strength of approximately 300 MBq. Local shielding is specified to reduce exposure rates to less than 50 µSv hr^{-1} at 30 cm from the shielding (the DOE threshold for designation as a radiation area). The results of the MDL calculations for ^{60}Co are scaled and used below to provide a consistent set of bounding conditions for AML. Additional MCNP6 calculations were made for AML to determine the annual dose outside the facility from scattered photons passing through the outside door and the annual doses on the mezzanine and in the basement.

Application of MDL Calculations to AML

Results of MDL calculations are given in Table 2 for solid concrete and for a concrete masonry unit (CMU) with and without grout fill. The dimensions of the CMU are given in Fig. 1. The MDL results are scaled and applied to determine the shielding needed at AML to reduce the annual dose to less than 0.2 mSv outside of controlled areas. The stairs shown in Figure 8 behind the hoods and gloveboxes increase the distance to the outdoor areas, reducing the exposure to members of the public outside the facility. Except for maintenance activities such as mowing the grass or repairing the exterior of the AML, there is no planned need to occupy the area immediately outside of the AML. The Argonne RSO has provided design guidance for AML. For outside areas the occupancy factor is 1/40. AML occupancy factors are provided in Table 7.

Table 7. AML occupancy factors based on Argonne radiation safety officer guidance and projected operations

Location	Occupancy factor	Hours per year
AML	1	2,000
Basement	0.025	50
Mezzanine	0.025	50
Mechanical Room	0.05	100
Contaminated Waste Transfer Area	0.025	50
Buffer Zone	1	2,000
Electrical Room	0.05	100
Outdoor Areas	0.025	50

The following new Argonne requirement was added which was not required for the MDL: The DOE design objectives criteria for the AML must be met when the source is placed at the minimum distance from the receptor.

If the source is placed at the back of the hood rather than at the center, the maximum calculated annual dose outside the facility dose is 0.21 mSv. This dose is slightly above the 0.2 mSv criterion. To ensure the dose is below the criterion, the hood is moved away from the wall. If the hood is moved 7.6 cm from the wall, the total distance is 242 cm and maximum annual dose is 0.197 mSv which meets the criterion. Increasing the lead shielding to 8.5 cm meets the criterion 30 cm from the front face of the hood with the lead placed 15.2 cm inside the hood, the minimum distance to maintain laminar air flow. The glove boxes and fume hoods specified for AML will support local shielding weighing 976 kg/m^2. This is sufficient to support the required shielding.

Grouted CMU is specified for the AML walls as shown in Figure 9. Annual calculated dose rates in outside areas (Table 8 and Fig. 9) are less than the design criterion of 0.2 mSv. Work with sources producing dose rates approaching 1 mSv hr^{-1} is only done in fume hoods. Therefore, distances to the receptors are determined from the closest locations in the hoods.

The basement and mezzanine are designated controlled areas as a result of radiological work which will be performed there. These areas meet the design objectives criteria with the distance to the receptor in the basement taken to the top of the head of a worker 196 cm tall, 99th percentile in height, Fig.10 (NHANES 2016). The Electrical Room and the Mechanical Room meet the design objectives criteria, but are not designated controlled areas. The dose rate for the Buffer Zone (Fig. 9) is calculated for an unshielded source. The Buffer Zone and the area in front of the hood meet the design criterion of 5 μSv hr^{-1} for a continuously occupied radiological area (2,000 hr y^{-1}).

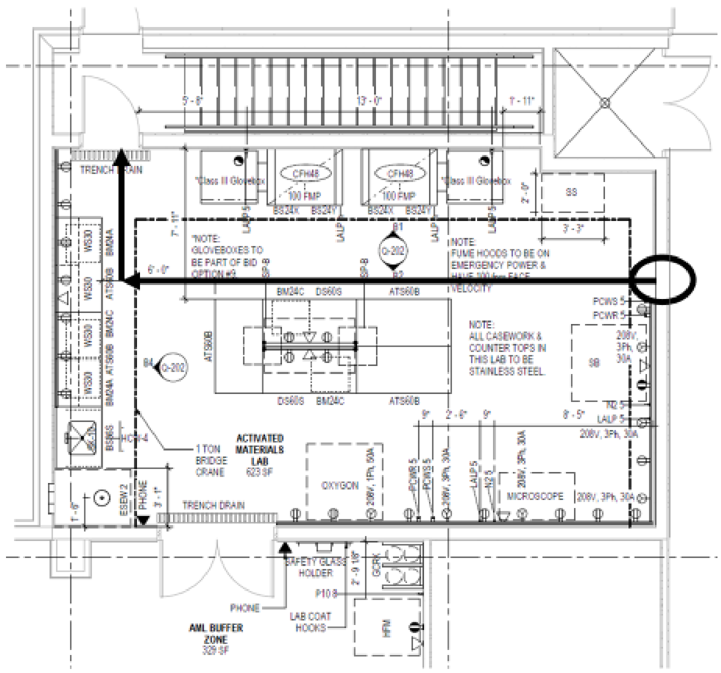

Fig. 8. AML plan view **after** moving emergency egress door – circle and arrow show locations

Table. 8. AML calculated annual doses

Location	Distance from Source to Receptor (cm)	Location (Figs. 9 & 10)	Annual Dose (mSv)
AML Area in Front of Hood	54	A	7.00

Contaminated Waste Transfer Area	185	B	0.34
Mechanical Room	398	C	0.15
Electrical Room	555	D	0.07
Buffer Zone	555	E	5.84
Outdoor Area in West Parking Lot	408	F	0.07
Outdoor Area Near Egress Door	379	G	0.02
Outdoor Area Behind Hood	242	H	0.20
Mezzanine	154	I	0.13
Basement	185	J	0.16

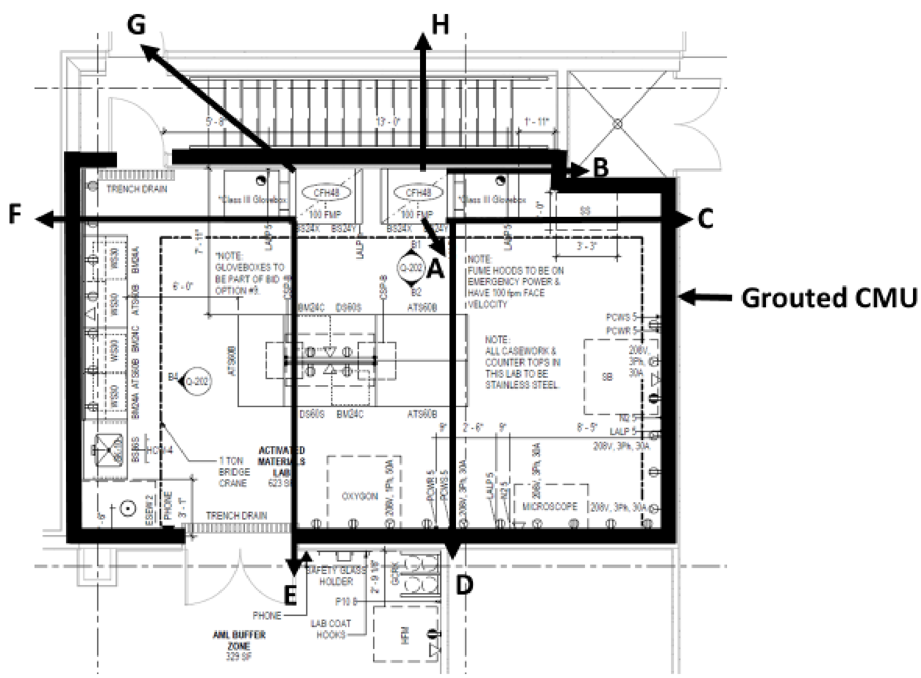

Fig. 9. AML plan view showing grouted masonry wall and calculated dose locations

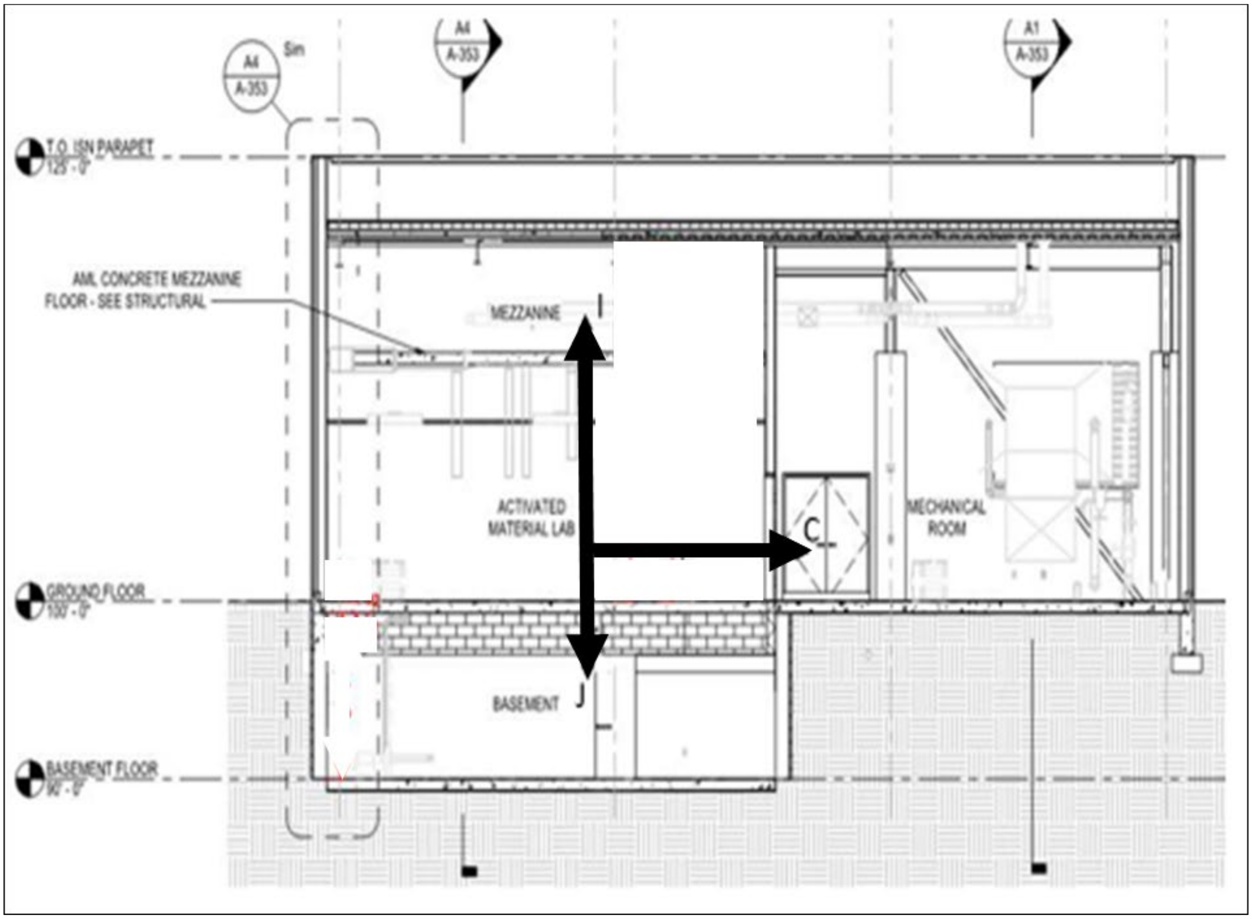

Fig. 10. AML elevation view showing calculated dose locations

AML Design Modifications

The maximum strength of the ^{60}Co source for AML is 300 MBq or about eight times the maximum ^{60}Co strength for MDL. For MDL local lead shielding was specified inside the fume hood or ^{60}Co glove box to lower the dose rate to 50 μSv hr^{-1} in all directions. For AML the initial design called for local shielding in all directions, but it was possible to meet the design objectives criteria by only specifying lead shielding between the source and the worker in front of the fume hood, working on the radioactive sample. This was accomplished by making two modifications during the design review which significantly reduced the local shielding required to meet the ALARA design objectives criteria. The first design modification made this possible by placing the hoods near the stairs (Fig.8) and using grouted CMU for the walls (Fig. 9). The second modification moved the emergency egress door from the wall between AML and the Mechanical Room to the wall near the AML outside door (Fig.8). As a result, the maximum annual dose in the Mechanical Room meets the design criterion (Fig. 9 and Table 8).

By using the same philosophy, building materials, and essentially the same equipment specifications, the project was able to reduce the number of computer calculations. The following additional MCNP6 calculations were made:

a. The dose rate outside the facility after the emergency egress door was moved was calculated because a similar calculation to account for the scattering from the grouted CMU walls was not made for MDL.
b. The dose rates in the basement and on the mezzanine needed to be calculated.

As a result of the reduced scope of the calculations, funds spent on AML calculations were in line with the lower overall cost of the that project.

DISCUSSION

DOE ALARA design criteria are set at 20% of the dose limits. However, additional constraints were added in the design of the new facilities described in this paper. These requirements are as follows:

1. Worst case sources were chosen.
2. A stationary receptor was used.
3. Maximum possible time for source exposure was used.
4. For AML the minimum distance between source and receptor was required. The location of the source in the hood was moved to achieve the minimum distance. For MDL the source was located at the center of the tray in the hood and 100 cm above the floor. Also for MDL, the receptor was located at the center of the corridor rather than at 30 cm from the grouted CMU wall.

Requirement 4 above introduces a new level of conservatism in addition to designing to meet the DOE criteria with the source in the hood for the entire occupancy time (Requirement 3). Neither of these requirements is found in the DOE Orders providing guidance and a graded approach is permitted [DOE 2020]. For the MDL Rad Lab, a transuranic materials research lab, most of the gamma rays emitted will be of lower energy than ^{60}Co gamma rays. Since lower energy gamma rays require less shielding to attenuate, the gamma dose will be overestimated. For AML ^{60}Co is the appropriate source; however the source strength is expected to be lower than the maximum for most of the samples processed. For AML the time spent working with the sources is expected to be 200 hours in a year or 10% of the time used in the calculations. For MDL the time is greater than 200 hours total but the time in a particular hood or glove box will be less. The process calls for the source to move from one hood or glove box to another. Thus, the dose for a particular receptor is overestimated.

Another issue is application of the occupancy factor. A person working at a desk in an office spends much more time in a radiation field from a point source located nearby than a worker on the maintenance floor who spends time at varying distances from the point source. The occupancy factors used in the design calculations did not take this into account. A stationary receptor was used and the source was assumed to be in the closest fume hood (or glove box for MDL) for the entire time (Requirements 2 and 3). Performing the worst case calculations demonstrated that it is not necessary to make calculations for every penetration. However, this conservative approach could add to the costs in cases where the areas are not controlled areas.

As mentioned, for MDL the location of the furniture in one of the offices reduced the distance between source and receptor, requiring the addition of grout to the CMU to meet the DOE criteria. For AML the hoods and glove boxes were moved from an outside wall to an interior wall with a staircase between in order to meet the criteria. To meet the Argonne requirement for minimum distance between source and receptor in addition to the DOE requirements, the AML hoods were moved out an additional 7.6 cm from the wall. Also, the emergency egress door was moved rather than adding shielding material in the door. Making the calculations and adjustments at an early stage in the building design (50% of final) facilitated making the changes without significantly increasing the costs.

Operational Considerations

The work planning and control procedure at Argonne is as follows:

a. The design basis is spelled out in the design report with accompanying documentation.
b. The report is reviewed and approved by the ALARA Facility Design and Modifications Committee and the Argonne Radiation Safety Officer with DOE field office concurrence.
c. The design report and the as-built drawings are incorporated into the facility safety documentation and work procedures.
d. Limitations and assumptions are captured to ensure that operations are conducted in accordance with the design basis.
e. Verification of as-built parameters is performed using area monitoring, such as with passive and active dosimetry.
f. Any operations and/or operational changes which could increase radiation exposures are investigated and mitigated.

CONCLUSIONS

The DOE design objectives criteria were met for the Materials Design Laboratory and the Activated Materials Laboratory. For members of the public the design objective is 0.2 mSv yr^{-1}. This objective was met in the offices on the Rad Lab floor as well as in the offices on other floors, primarily due to the inverse square of the distances decrease for point sources. The shielding philosophy provided consistency. Sufficient local shielding was used to reduce the dose rate to below 50 μSv hr^{-1} at 30 cm (the threshold for designation as a radiation area). The

MCNP6 computer program was used for the shielding calculations for both projects. Fume hoods and glove boxes were designed to support the weight of the shielding materials for worst case sources. Furthermore, by using the same philosophy, building materials, and essentially the same equipment specifications as used for MDL, the smaller AML project was able to reduce the number and cost of computer calculations. Using a shielded storage location for sources when not in use helped ensure that design objectives criteria were met.

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