DEPARTMENT OF THE AIR FORCE
AIR FORCE INSTITUTE FOR OPERATIONAL HEALTH (AFMC)
BROOKS CITY-BASE TEXAS

30 March 2007

MEMORANDUM FOR MR. BENTON WILMOTH
88 ABW/CEVO
WRIGHT-PATTERSON AFB OH 45433

FROM: AFIOH/SDR
2350 Gillingham Drive
Brooks City-Base, TX 78235-5103

SUBJECT: Consultative Letter, IOH-SD-BR-CL-2007-0037, Review of Design of New Wright-Patterson Air Force Base (WPAFB) Non-Destructive Inspection (NDI) Facility

1. The Air Force Institute for Operational Health (AFIOH), Radiation Surveillance Division (SDR), Health Physics Consulting Branch (SDRH) performed a partial assessment of the design of the new NDI facility at the WPAFB at the request of Mr. Benton Wilmoth, 88ABW/CEVO. The request was to evaluate the adequacy of the amount of shielding in the facility if the primary beam was only directed at the floor.

2. The evaluation was based on the following provided information:

a. The entire NDI facility will be located inside an aircraft hangar. The NDI exposure room is oriented with a sliding door on the North Wall (highlighted area in Attachment #1). External dimensions for the exposure room are: 27’11” long x 18’4” wide x 16’ high.

b. Three of the walls (north, east and west) around the exposure room require shielding to meet unrestricted area requirements (0.1 rem/year from Table A4.1, AFI 48-148). The South Wall is common to both the NDI Control Room and the Film Processing Room. Since those areas will only be occupied by NDI personnel when x-rays are generated, the South Wall could be designated a restricted area.

c. The beam will only be directed toward the floor and there will be a locked fence on the roof to maintain a restricted area over the exposure room. Therefore, shielding provided by the ceiling need only consider leakage and scatter radiation to a restricted area.

d. The x-ray device to be used is a Lorad LPX-160. Projected maximum workload and technique settings are:

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- 12 exposures/day = 60 per week = 240 per month = 2880 per year
- 2.0 minutes per exposure
- 160 kVp at 5.0 mA

e. The tube head will always be located in the center of the exposure room. At times, it may be elevated as much as 8’ off the floor. Therefore, the distance from the tube head to each wall is approximately:

- North (sliding door) Wall = 14’ (shield for unrestricted area requirements)
- South Wall = 14’ (shield for restricted area requirements)
- East Wall = 9’4” (shield for unrestricted area requirements)
- West Wall = 9’4” (shield for unrestricted area requirements)
- Ceiling = 8’ (shield to meet only leakage and scatter radiation to restricted area requirements)

f. Current plans include the use of one layer of 1/2" gypsum board over standard hollow cinderblock with 1/16" lead shielding sandwiched between them. The personnel door on the south wall will be a standard one (1) hour fire rated fire door containing 1/8” of lead. The sliding door on the north wall will be a 1 ¾” hollow metal door with 1/8” lead lining.

g. SDRH has previously evaluated the Lorad LPX-160 system at other locations, and historically it has an average output of 60 R/min at 1 meter.

3. Findings:

a. IAW Technical Order 33B-1-1, *Nondestructive Inspection,* Air Force Instruction (AFI) 48-148, *Ionizing Radiation Protection,* and National Council on Radiation Protection, and Measurement (NCRP) Report 116, *Limitation of Exposure to Ionizing Radiation,* persons in uncontrolled areas should not receive a dose in excess of 100 mrem in one year (100 mrem/year). The weekly dose limit would be 2 mrem/week should a person work 50 weeks per year. Additionally, the dose shall not exceed 2 mrem in any one hour.

b. All calculations were done using the assumptions that the tube head would be located in the center of the room at a height of 8’ above the floor and only directed at the floor. The floor of the room was considered the primary barrier; therefore, only leakage and scatter upon the secondary barriers was considered. Figure 15.3 from *Atoms, Radiation, and Radiation Protection, Second Edition* (Turner, 2004) was used to determine that 5.6 mm (~7/32-inch) of lead would be required. The most limiting distance was the distance from the floor to the ceiling and this was the distance chosen to calculate the required shielding. All of the calculations were done with the assumption that all of the secondary barriers were at the same 8’ distance to be conservative. The present design for the facility was found to be sufficient for the given application. The design would require no additional shielding. The calculations indicate that 7.44 HVLs of lead are required to shield personnel from secondary radiations. The present design has approximately 7.5 HVLs of lead equivalent shielding.

c. There was no information provided concerning the design of the doorways or wall penetrations for utilities to evaluate their adequacy.

4. Recommendations:

a. The facility design is sufficient to prevent personnel dose from exceeding the 100 mrem/yr limit based on the supplied information and the stated assumptions. The facility should have a radiation survey performed and documented prior to placing it into operation.

b. This evaluation was based on the provided information that the primary beam would only be directed at the floor of the facility. These calculations are only valid when the beam is directed at the floor of the facility. Usage of the facility in any other configuration would require further evaluation.

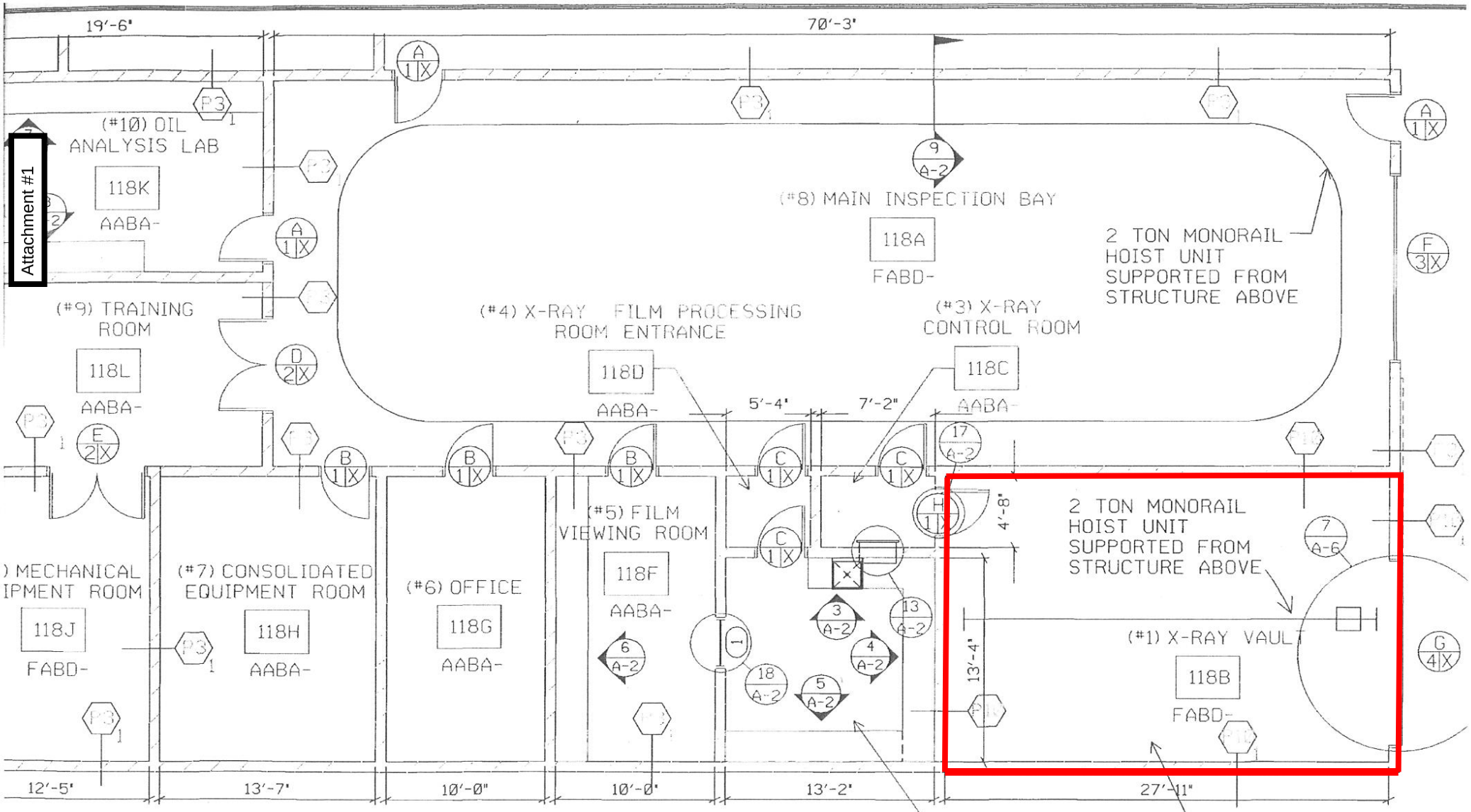
c. If you have any comments or questions regarding this consultation, please contact Mr. Brian Harcek at 210-536-4263 (DSN 240-4263).

//signed//

SCOTT M. NICHELSON, Lt Col, USAF, BSC, CHP, CIH
Chief, Radiation Surveillance Division

Attachments:
1. Facility Drawing
2. Calculations

Attachment #1



NDI SHOP ENLARGED FLOOR PLAN

1/8" = 1'-0"

NOTE: ALL WALLS ARE TYPE 'P3' UNLESS OTHERWISE NOTED

Attachment #2

$$K_{\mu x} = \frac{P(d_{pri})^2}{WUT} = (0.002 rem/wk)(2.4)^2/(600)(1)(1) = 1.92E-5$$

Where;

$K_{\mu x}$ = Exposure at unit distance and workload
P = Weekly dose rate (100 mrem/yr divided by 50 weeks per yr)
d_{pri} = Distance from source to protected person (2.4 m)
W = Weekly workload (60 shots/week, 2 minutes/exposure, 5 mA/exp)
U = Use factor (1)
T = Occupancy factor (1)

The most limiting distance based on the information provided is 8' (2.4 meters) to the ceiling. The roof of the structure will be a restricted access area. Utilizing the 200 kVp curve from Figure 15.3 from Turner, the necessary shielding is found to be 5.6 millimeters, or 0.22 inches of lead.

<u>Leakage</u>

$$B_{Lx} = P(d_{\sec})^2(60)I/YWT = (0.002)(2.4)^2(60)(5)/(1)(600)(1) = 5.76E-3$$

Where;

B_{Lx} = Leakage radiation transmission factor
P = Weekly dose rate (2 mrem/wk)
d_{sec} = distance to shield (2.4 m)
I = Average beam current in mA (5 mA)
Y = Manufacturer maximum design limit for radiation leakage (assume 1)
W = Weekly workload (60 shots/week, 2 minutes/exposure, 5 mA/exp)
T = Occupancy factor (1; most conservative)

The number N of half-value layers that reduces the radiation to the factor *B* of its unshielded value is given by $B = 2^{-N}$, or $N = -\frac{\ln B}{0.693}$.

$$N = -\frac{\ln B}{0.693} = -\frac{\ln 5.76E-3}{0.693} = 7.44 \text{ HVL}$$

<u>Scatter</u>

$$K_{\mu x} = \frac{1000P(d_{\sec})^2}{fWT} = 1000(0.002)(2.4)^2/(1)(600)(1) = 1.92E-2$$

Where;

$K_{\mu x}$ = Exposure at unit distance and workload
d_{sec} = distance to shield (2.4 m)
f = 1 (for ≤500 kVp from Table 15.6 in Turner)
W = Weekly workload (60 shots/week, 2 minutes/exposure, 5 mA/exp)

T = Occupancy factor (1; most conservative)

From Turner Figure 15.3, the required thickness of lead is 0.5 mm. This is equivalent to 0.96 HVLs.

Since the difference between the scatter and leakage barrier thicknesses is more than 3 HVLs, the larger of the two will provide protection from secondary radiation. Turner states that a HVL of lead is equal to 0.52 mm for a peak voltage of 200 kVp. Thus the required lead shielding, or equivalent in the walls due to leakage and scatter is 3.87 mm (0.15 inches). One sheet of 5/8-inch gypsum wallboard is approximately equivalent to 1/32-inch of lead.

Broad beam attenuation

$$I = BI_0 e^{-\mu t}$$

Where;

B = build-up factor
I_0 = intensity of beam entering material
I = intensity of beam transmitted through the material
t = thickness of material
μ = linear attenuation coefficient of the material

Assuming that B = 1.0 and solving for t, we obtain the following;

$$t = \frac{\ln(I/I_0)}{-\mu} = \frac{\ln(2.0E-3/3.204E3)}{-20.8} = 0.687cm$$

The build-up is determined using Turner as a reference to relate to μt. Then using the original equation we calculate the intensity of the beam transmitted through the shielding.

$$I = BI_0 e^{-\mu t} = 2.42(3.204E3)e^{-(12.704)} = 0.0447R/wk$$

Since this yields a value that is greater than the limit of 2E-3 R/wk, it is necessary to calculate the intensity using different values for the relaxation length and build-up.

$$I = BI_0 e^{-\mu t} = 2.66(3.204E3)e^{-(15.5)} = 1.58E-3R/wk$$

References

1. *Structural Shielding Design for Medical X-Ray Imaging Facilities,* NCRP Report No. 147, September, 2004
2. *Atoms, Radiation, and Radiation Protection, Second Edition,* James E. Turner, 2004