Appendix A3 Radiation Dose to the Truck Driver

This appendix summarizes a dose assessment for workers exposed to yellowcake (U_3O_8) stored in 55-gallon drums; the dimensions of a steel drum are (S. Cohen 2005):

Height = 86.36 cm (34 inches)
Diameter = 57.15 cm (22.5 inches)
Drum wall thickness = 0.15189 cm

The effective dose was estimated for workers exposed to the waste in the following scenarios:

1) Truck driver transporting 60 steel drums containing yellowcake. The drums are transported in a 40 foot trailer

For this assessment, it was assumed that a truck driver is expected to make 3 out of 15 total deliveries per year from the mill site to a conversion facility in Metropolis, Illinois. The 26-ton truck contains approximately 60 drums (55 gallon) of yellowcake. The estimated exposure time while driving or resting in the cabin is approximately 22 hours per delivery. In addition, the truck driver will perform a load inspection prior to departure and upon arrival at the destination; each inspection was assumed to take 30 minutes.

2) Forklift driver operating a forklift to move 60 drums from the truck

The estimated exposure time for the forklift driver moving the drums from the truck is 5 minutes per drum. It was conservatively assumed that one worker operates the forklift to move all the drums from one truck for each delivery. Therefore, the exposure time is approximately 5 hours (300 minutes) per delivery and 75 hours per year (i.e., 5 hours per delivery x 15 deliveries per year).

3) Truck driver transporting uranium ore in a dump truck

The truck driver is expected to drive 3 hours per day and 200 days per year. Therefore, exposure time 600 hours per year.

The dose assessment was performed using MicroShield Version 8.02 (Grove Software 2009). The assumptions used in the MicroShield runs for each scenario are described below.

1.0 Estimated Effective Dose to Workers

1.1 Truck Driver – Trailer with Drums Containing Yellowcake

During the transport of yellowcake, the worker is exposed while driving the trailer and while performing inspections.

Source Geometry

The internal dimensions of a 40 foot trailer according to (APL Limited 2009) are:

Length	= 1203.2 cm
Width	= 235.2 cm
Height	= 238.5 cm

Other source geometry assumptions included:

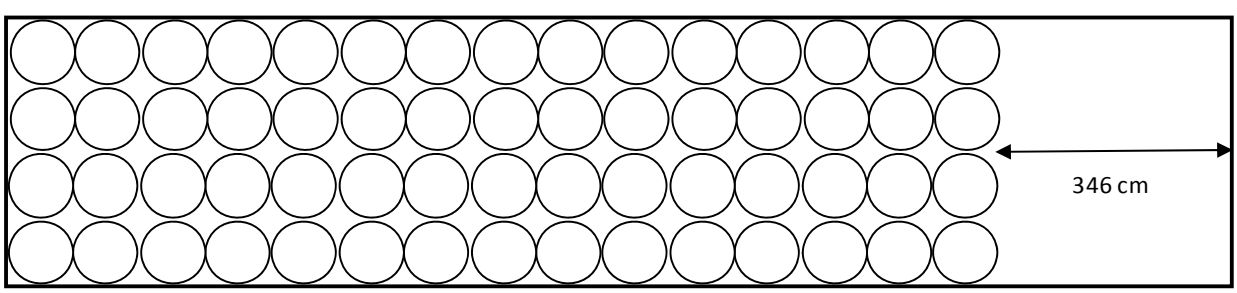
- The walls of the trailer are 1/8th inch (0.3 cm) thick steel; and,
- The wall of the cab was assumed to provide an equivalent of 1/8th inch (0.3 cm) thick steel.

Inside the trailer, the maximum numbers of drums that can fit along the width is four drums. The numbers of drums along the length varies for each scenario and is described below.

There are 60 drums containing yellowcake. For the MicroShield run, the source geometry used was a rectangular volume; the drums are arranged in a 15 (length-wise) by 4 (width-wise) configuration as shown in Figure A3.1. The dimensions of the source are:

Length	= 857.25 cm (i.e., diameter of 1 drum (57.15 cm) x 15)
Width	= 228.6 cm (i.e., diameter of 1 drum (57.15 cm) x 4)
Height	= 86.36 cm (i.e., height of 1 drum (86.36 cm)

Figure A3.1 Drums Containing Yellowcake in Trailer



Source Material

For the MicroShield calculations, U_3O_8 was used for yellowcake.

Source Radionuclides

The yellowcake was assumed to have U-238, U-234, and U-235 present at natural abundances. U-238 was assumed to be in equilibrium with its short-lived decay products; Th-234, Pa-234m, Pa-234 (which has a relative concentration of 0.16% of U-238) and U-234. U-235 was assumed to be in secular equilibrium with Th-231. The concentration of each radionuclide was calculated as shown in equation 1.

$$C_{radionuclide}\left(\frac{Bq}{cm^3}\right) = Activity_{radionuclide}\left(\frac{Bq}{g}\right) \times \rho_{yellowcake} \times \text{Fraction of U in } U_3O_8 \quad (1)$$

where:

$Activity_{radionuclide}$ = Provided in Table 1

$\rho_{yellowcake}$ = 2.055 g/cm^3

Fraction of U in U_3O_8 = 0.848

The concentrations of radionuclides are shown in Table A3.1.

Table A3.1 Activity Concentrations of Radionuclides in Yellowcake

Nuclide	Branching Ratio	Specific Activity (Bq/g)	Concentration (Bq/cm^3)
U-238	1	1.23E+04	2.15E+04
Th-234	1	1.23E+04	2.15E+04
Pa-234	0.0016	1.98E+01	3.44E+01
Pa-234m	1	1.23E+04	2.15E+04
U-234	1	1.23E+04	2.15E+04
U-235	0.046	5.68E+02	9.90E+02
Th-231	0.046	5.68E+02	9.90E+02

Dose Points

Driving: During the time spent driving, the worker is located in the cab of the truck and is exposed from behind (i.e., drivers back towards the width of the source). The driver's cabin was assumed to be 150 cm from the trailer. However, it should be noted that the actual distance from the source is 516.6 m when the thicknesses of the steel wall of the trailer (0.3 cm), wall of the cab (0.3 cm), the space between the driver and the back wall of the cab (20 cm) and the space between the first row of drums and front wall of the trailer (346 cm) are included. In addition, for conservative purposes the worker was assumed to be located at the centre point of the shorter side (width) of the trailer (i.e., half-width and half-height of the source).

Inspection: The driver inspects the truck; prior to departure and upon arrival at the destination. During the inspection, the driver was assumed to be 50 cm away from the side of the truck. In addition, for conservative purposes the worker was assumed to be located at the centre point of the longer side (length) of the trailer (i.e., at half-length and half-height of the source).

Build-up

The build-up material varies for each case. For conservative purposes the material which resulted in the highest effective dose rate was used as the build-up material.

Integration

The integration parameters in the X, Y, and Z direction varied for each case. The integration parameter values were increased until the effective dose converged.

Results

The effective doses to the worker while driving the truck are provided in Table A3.2. The postero-anterior effective dose rate was used because the worker is exposed from behind while driving and the antero-posterior dose rate was used for the worker exposure while inspecting the truck to be conservative.

Table A3.2 Effective Dose to Truck Driver (Scenario 1)

Activity	Hours per delivery	Effective Dose Rate (mSv/hr)	Effective Dose (mSv/delivery)
Driving	34	4.065E-04[b]	1.38E-02
Inspection	1[a]	1.73E-02[c]	1.73E-02
		Total per delivery[d]	3.11E-02
		Deliveries per year	15
		Total per year (mSv/y)[e]	0.467

Note: the values in the table were rounded.

a) 0.5 hours prior to departure and 0.5 hours upon arrival at the destination.

b) Postero-anterior geometry (with build-up).

c) Antero-posterior geometry (with build-up).

d) Sum of driving and inspection effective dose.

e) Total per delivery x Deliveries per year.

1.2 Forklift Driver – Moving Drums Containing Yellowcake

MicroShield was used to estimate the effective dose to a worker who is exposed to a drum containing yellowcake while operating a forklift to move drums from the truck.

Source Geometry

For MicroShield, a cylinder volume - side shields was used for the source geometry. The dimensions of a drum are provided in Section 1.1. As mentioned, the forklift driver moves 60 drums containing yellowcake.

Source Material

The activity concentrations of all radionuclides in yellowcake are provided in Section 1.1, Table A3.1.

Dose Points

The worker driving a forklift will be exposed from the front of the source and was assumed to be 100 cm from the drum. In addition, for conservative purposes the worker was assumed to be located at the centre point of the drum (i.e., half-width and half-height of the source).

Build-up

The build-up material varies for each case. For conservative purposes the material which resulted in the highest effective dose rate was used as the build-up material.

Integration

As described in Section 1.1, the integration parameters in the X, Y, and Z direction varied for each case. The integration parameter values were increased until the effective dose converged.

Results

The effective doses to the worker while operating a forklift are provided in Table A3.3. The antero-posterior effective dose rates were used because the worker is exposed from the front while operating the forklift.

Table A3.3 Effective Dose to Forklift Driver (Scenario 2)

Effective Dose Rate (mSv/hr), Antero-posterior geometry (with build-up)	1.89E-03
Hours Spent Moving Drums per Delivery	5
Total Effective Dose Rate per Delivery[a] (mSv/delivery)	4.72E-03
Deliveries per year	15
Total Effective Dose Rate per Year (mSv/yr)	0.07

Note: the values in the table were rounded.

a) The effective dose was calculated by multiplying the antero-posterior effective dose rate (with build-up) by the number of hours the worker, and a shielding factor of 0.5 (i.e., the transmission of radiation through and around shielding provided by the forklift[3]).

1.3 Truck Driver – Dump Truck with Uranium Ore

During the transport of uranium ore containing 0.23% U_3O_8, the worker is exposed while driving the trailer.

Source Geometry

For the MicroShield run, the source geometry used was a rectangular volume. The dimensions of the dump box and pup (i.e., source) were calculated based on the mass of the ore in the dump box (15 tons) and pup (12 tons) and assumed bulk density of the ore (1.9 g/cm^3) and are:

For dump box:

Length = 350 cm
Width = 200 cm
Height = 105 cm

For pup

Length = 280 cm
Width = 200 cm
Height = 105 cm

Other source geometry assumptions included:

- The walls of the trailer are 1/4th inch (0.6 cm) thick steel; and,
- The wall of the cab was assumed to provide an equivalent of 1/8th inch (0.3 cm) thick steel.

3 Mascanzoni (1989) measured the transmission of photons from ground-level sources to the operator's seat in a conventional tractor. The result showed that the tractor shield more than 60% of the radiation. Considering the differences in geometry between a tractor and a forklift, and source geometry, a lower shielding factor of 50% was credited for the calculations.

Source Material

For the MicroShield calculations, SiO_2 was used as a surrogate for the bulk ore.

Source Density

The bulk density of the ore is 1.9 g/cm^3.

Source Radionuclides

The ore was assumed to have U-238 and all its decay products in equilibrium. The U-238 concentration in ore (45.755 BqU-238 per cm^3) was calculated as shown in equation 2. (The concentrations of the U-238 decay products were generated in MicroShield by doubling the calculated U-238 concentration and decaying U-238 for one half-life (4.47 x 10^9 y)).

$$C_{U\text{-}238}\left(\frac{\text{Bq U-238}}{\text{cm}^3}\right) = 1.2347\times10^4\left(\frac{\text{Bq U-238}}{\text{gU}}\right)\times\text{Ore grade}\left(\frac{\text{gU}_3\text{O}_8}{\text{g ore}}\right)\times\text{Fraction of U in U}_3\text{O}_8\left(\frac{\text{gU}}{\text{gU}_3\text{O}_8}\right)\times\rho_{ore}\left(\frac{\text{g ore}}{\text{cm}^3}\right) \quad (2)$$

where:

1.2347 x 10^4	=	Specific activity of U-238
Ore grade	=	0.0023
Fraction of U in U_3O_8	=	0.848
ρ_{ore}	=	1.9 g/cm^3

Dose Points

During the time spent driving, the worker is located in the cab of the truck and is exposed from behind (i.e., drivers back towards the width of the source). The driver's cabin was assumed to be 150 cm from the trailer. However, it should be noted that the actual distance from the source is 170.6 m when the thicknesses of the steel wall of the trailer (0.3 cm), wall of the cab (0.3 cm), the space between the driver and the back wall of the cab (20 cm). In addition, for conservative purposes the worker was assumed to be located at the centre point of the shorter side (width) of the trailer (i.e., half-width and half-height of the source).

Build-up

The build-up material varies for each case. For conservative purposes the material which resulted in the highest effective dose rate was used as the build-up material.

Integration

The integration parameters in the X, Y, and Z direction varied for each case. The integration parameter values were changed increased until the effective dose converged.

Results

The effective doses to the worker while driving the truck are provided in Table A3.4. The postero-anterior effective dose rate was used because the worker is exposed from behind while driving and the antero-posterior dose rate was used for the worker exposure while inspecting the truck to be conservative.

Table A3.4 Effective Dose to Truck Driver (Scenario 3)

Effective Dose Rate (mSv/hr), Postero-anterior geometry (with build-up)	7.99e-4
Hours per day	3
Total Effective Dose Rate per delivery (mSv/delivery)	2.40E-3
Delivery days per year	200
Total Effective Dose Rate per year[a] (mSv/yr)	0.48

Note: the values in the table were rounded.

a) Total per delivery x Deliveries per year.

2.0 Summary

The annual effective doses for Scenarios 1 and 2 are provided in Table A3.5.

Table A3.5 Annual Effective Dose

Receptor	Effective Dose, mSv/y (mrem/yr)
Truck Driver - Trailer with Drums Containing Yellowcake	0.394 (39.4)
Forklift Driver - Moving Drums Containing Yellowcake	0.07 (7)
Truck Driver - Dump Truck with Uranium Ore	0.48 (48)

3.0 References

Grove Engineering 2009. *MicroShield Version 8.02*

Mascanzoni, D. 1989. *Structure Shielding of a Tractor against Ground-Deposited Radioactive Fall-out.* J. Radiol. Prot., Vol. 9, pages 237-240.

S. Cohen and Associates 2005. *Report to the Advisory Board on Radiation and Worker Health*. Document No. SCA-TR-TASK-CNPIID. February.

APL Limited 2009. *http://www.apl.com/equipment/html/equipment_specs_standard.html#48HC*.