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United States Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Reference: University of Maryland, Maryland University Training Reactor ("MUTR"), Docket No. 50-166, License No. R-70, Technical Specifications, Response to February 18, 2011, Request for Additional Information ("RAI") Regarding Remaining Technical Specifications

The University of Maryland herewith submits the following documents in connection with its application for a renewal of the MUTR license identified above:

1. Tentative schedule for Ar-41 Measurement and Analysis and
2. Response to the NRC Request for Further Information Regarding the Dose to Workers, Members of the Public and the Nearest Residence during Normal Operations and during an MHA Incident at the University of Maryland Training Reactor.

If you have questions about these submittals, please write me at 2309F Chemical & Nuclear Engineering Building, University of Maryland, College Park, MD 20742-2115 or email me at mohamad@umd.edu. Please copy Prof. Robert Briber on any correspondence: 2135 Chemical & Nuclear Engineering Building, University of Maryland, College Park, MD 20742-2115; rbriber@umd.edu.

I declare under penalty of perjury that the foregoing and the enclosed documents are true and correct.

Sincerely,

Mohamad Al-Sheikhly
Professor and Director
Maryland University Training Reactor

Enclosures (2)
cc: Robert Briber

ADZD
NRR

Tentative Schedule for Ar-41 Measurement and Analysis

Fission chamber delivery – week of 4 July
Ex-reactor operational testing, final assembly, installation into reactor – completed by 22 July
In-core testing and calibration – completed by 29 July

Reactor operation (various power levels/run times), sample collection and analysis – completed by 19 August

Final dose calculations and assessment, final report – completed by 31 August

Response to the NRC request for further information regarding the dose to workers, members of the public and the nearest residence during normal operations and during an MHA incident at the UMTR, University of Maryland Training Reactor.

Sources of radiation during normal and MHA conditions:

During normal operations in the reactor facilities, Ar-41 is produced primarily from irradiation of dissolved argon gas in the reactor pool, a fraction of which eventually evolves into the air of the reactor bay. This evolution results from the reduced solubility of argon gas in water as the water temperature increases. Additionally, Ar-41 can be generated from activated argon in air filled cavities such as the thermal column, beam-ports, and through-tube. These auxiliary systems are utilized in approximately 1% of experiments and therefore contribute a negligible amount of Ar-41 to the reactor bay in comparison to the pool generation and diffusion from the pool to the air volume in the reactor.

The UMTR is capable of exhausting the air in the reactor bay via two exhaust fans mounted on the side of the reactor building. The fans exhaust at a rate of 2.83 m^3/s. During normal operations the fans are not in operation. Two conditions exist for the normal operation and MHA event: Ventilation ON (fans running), and Ventilation OFF (fans turned off). In the case of Ventilation OFF, a conservative assumption is made that there will be leakage at a rate of 5% per hour out of the reactor bay through several cavities such as the entrance/exit doors on the ground floor and upper balcony level as well as the roll up door on the ground floor of the reactor bay.

The Maximum Hypothetical Accident, MHA that could occur as stated in the SAR is a fuel element manipulation incident that results in the failure of one fuel element in air with subsequent release of isotopes into the reactor bay volume. Values of the release of isotopes are listed in tables 13.1-13.3 of the SAR. There are 6 conditions that are considered in regards to doses to the operator, nearby member of the public and nearest residence for both an MHA and for normal operations.

During an MHA and during Normal Operations:

1. Occupational dose to workers ventilation ON
2. Occupational dose to workers ventilation OFF
3. Maximum dose to the public at the nearest residence ventilation ON
4. Maximum dose to the public at the nearest residence ventilation OFF
5. Maximum dose to a member of the public adjacent to MUTR ventilation ON
6. Maximum dose to a member of the public adjacent to MUTR ventilation OFF

Action taken, assumptions, formulas, and reference data are as follows:

- The production rate as stated in the SAR for Ar-41 in the reactor pool during normal operations is 0.1 Ci / 30 MWhrs operation. This rate is utilized to determine the steady state equilibrium rate of Ar-41 generation in the pool for 250 kw, 365 days, 24 hours per day for a whole year
- Total Effective Dose Equivalents (TEDE) is the sum of external dose as well, (DDE) and the internal Committed Effective Dose Equivalent (CEDE);
- Building Leakage was assessed at 12 different locations in the Reactor building utilizing Drager smoke emitting air current tubes to observe the flow and direction of smoke in the reactor bay;
- A leakage rate of .05/hr was assumed out of the reactor bay with ventilation OFF;
- Uniform mixing and instantaneous release of the nuclides during an MHA was assumed;
- Dose Conversion Factors (DCFs) reflect those contained in IAEA Safety Series No. 115, Federal Guidance Report 11 and ICRP 68 for the isotopes in question;
- The Occupational Dose to workers is taken over 2000 hours;
- The Gaussian Plume model and Pasquill Categories of Atmospheric Stability were utilized to determine maximum concentration downwind of the reactor for doses to the nearest residence;

DOSE CALCULATIONS

- <u>The Occupational internal dose to workers:</u>

$$D = C \bullet (Br) \bullet t \bullet (DCF)$$

Where:

D = Dose to the worker inside the reactor [rem]
C = concentration C_v, C_L ventilation and leakage [Ci/m^3]
Br = breathing rate [m^3/s]
DCF = Dose Conversion Factor [rem/Ci]
t = time to evacuate the building [s]

- <u>The Occupational external dose to workers:</u>

$$D\gamma\ [rads/s] = (0.057)\ E_{\gamma,\ avg}\ (MeV)\ \chi\ [Ci/m^3]$$

Where:

Dγ = Gamma dose rate from the cloud in [rads/s]

$E_{\gamma, avg}$ = Gamma ray energy in MeV

χ = the concentration in the cloud in [Ci/m^3]

$$D_\beta = 0.23 E_{avg} \chi \text{ [rads/s]}$$

Where:

D_β = Beta dose rate from the cloud in [rads/s]

E_{avg} = Average Beta ray in MeV

χ = the concentration in the cloud in [Ci/m^3]

- <u>The maximum dose to the nearest residence:</u>

Using the Gaussian Plume model for the ground level centerline concentration:

$$\chi = \frac{Q}{2\pi\sigma_y\sigma_z\mu} \text{EXP}\left(-\frac{y^2}{2\sigma_y^2}\right) \left[\text{EXP}\left(-\frac{(z-h)^2}{2\sigma_z^2}\right) + \text{EXP}\left(-\frac{(z+h)^2}{2\sigma_z^2}\right)\right]$$

For an elevated release, ventilation ON (fans running), and a center line concentration:

$$\chi = \frac{Q}{2\pi\sigma_y\sigma_z\mu} e^{-\frac{H^2}{2\sigma_z^2}}$$

For a ground release, ventilation OFF (leakage), and a center line concentration:

$$\chi = \frac{Q}{2\pi\sigma_y\sigma_z\mu}$$

The maximum ground level concentration occurs for $\sigma_z = H/\sqrt{2}$

Where H is defined as the effective height:

$$H = h + d \cdot (v/\mu)^{1.4}(1+\Delta T)/T$$

Where h = effective release height in meters
d = diameter of the outlet in meters

v = exit velocity of the gas m/s
μ = average wind speed m/s
ΔT = difference in the ambient and effluent gas temperature
T = temperature of the effluent gas

$$D = f_{rel} A \bullet (\chi/Q) \bullet (Br) \bullet (DCF)$$

Where:

D = Dose to the public outside the reactor [rem]
f_{rel} = fraction of activity released, f_v, f_L ventilation and leakage
A = total activity that could be released [Ci]
X/Q = atmospheric diffusion factor [s/m^3]
Br = breathing rate [m^3/s]
DCF = Dose Conversion Factor [rem/Ci]

- <u>The maximum dose to person in areas adjacent to MUTR</u>:

Condition: a member of the public located on the lower level outside the reception room on the south side of the reactor, figure 3.4 of the SAR: in the case of ventilation ON, the only source of exposure to the individual would be from shine inside the reactor bay. In the case of ventilation OFF the individual could receive an exposure from leakage out of the reactor and shine from source terms in the reactor.

Summary of doses:

MHA Summary

Occupational dose to workers ventilation ON = 219 mrem
Occupational dose to workers ventilation OFF = 278 mrem

Data
MHA CEDE (worker)

MHA

1.2.External Occupational Dose to Worker				Shallow Dose Equivalent SDE at 7 mg/cm^2						ON	OFF
Beta Dose rate from the Cloud (SDE = D_{β})				$D_{\beta} = 2.45 \times E\text{-}7\ C\ E_{avg}\ e^{-\mu \times 0.007}$ mGy/hr						SDE rem	SDE rem
		release	χ_0				Avg $\chi_{t\,w/v}$	Avg $\chi_{t\,w/L}$	Dose χ_0	Dose χ_v	Dose χ_L
Isotope	$E_{\beta,\,avg}$ (keV)	mCi	χ [Ci/m^3]	$\mu_{\beta,t}$	$e^{-\mu\beta,t \times 0.007}$	D_{β} [mGy/hr]	Vent factor	Leak factor	300s [rads]	300s [rads]	300s [rads]
Kr-85m	230	1.0760	6.3593E-07	3.3279E+01	7.9219E-01	1.0504E-03	7.870E-01	9.960E-01	8.7530E-06	6.889E-06	8.718E-06
Kr-85	228	0.0180	1.0638E-08	3.3702E+01	7.8985E-01	1.7367E-05	7.870E-01	9.960E-01	1.4472E-07	1.139E-07	1.441E-07
Kr-87	1329	2.0700	1.2234E-06	2.8316E+00	9.8037E-01	1.4450E-02	7.870E-01	9.960E-01	1.2041E-04	9.477E-05	1.199E-04
Kr-88	366	2.9590	1.7488E-06	1.7129E+01	8.8701E-01	5.1466E-03	7.870E-01	9.960E-01	4.2888E-05	3.375E-05	4.272E-05
Kr-89	1650	3.6380	2.1501E-06	2.1001E+00	9.8541E-01	3.1691E-02	7.870E-01	9.960E-01	2.6409E-04	2.078E-04	2.630E-04
Kr-90	800	4.1330	2.4427E-06	5.7229E+00	9.6073E-01	1.7019E-02	7.870E-01	9.960E-01	1.4182E-04	1.116E-04	1.413E-04
Xe-133	416	8.5160	5.0331E-06	1.4293E+01	9.0479E-01	1.7173E-02	7.870E-01	9.960E-01	1.4311E-04	1.126E-04	1.425E-04
Xe-135m	100	2.2430	1.3257E-06	1.1532E+02	4.4608E-01	5.3605E-04	7.870E-01	9.960E-01	4.4671E-06	3.516E-06	4.449E-06
Xe-135	302	3.8440	2.2719E-06	2.2510E+01	8.5422E-01	5.3128E-03	7.870E-01	9.960E-01	4.4274E-05	3.484E-05	4.410E-05
Sr-89	584	0.2500	1.4775E-07	8.8761E+00	9.3976E-01	7.3508E-04	7.870E-01	9.960E-01	6.1257E-06	4.821E-06	6.101E-06
Sr-91	1354	323.0000	1.9090E-04	2.7595E+00	9.8087E-01	2.2983E+00	7.870E-01	9.960E-01	1.9152E-02	1.507E-02	1.908E-02
Sr-92	1521	365.5000	2.1602E-04	2.3499E+00	9.8369E-01	2.9298E+00	7.870E-01	9.960E-01	2.4415E-02	1.921E-02	2.432E-02
Sr-93	1000	414.5000	2.4498E-04	4.1980E+00	9.7104E-01	2.1564E+00	7.870E-01	9.960E-01	1.7970E-02	1.414E-02	1.790E-02
Cs-134	156	0.8000	4.7281E-07	5.8735E+01	6.6289E-01	4.4322E-04	7.870E-01	9.960E-01	3.6935E-06	2.907E-06	3.679E-06
Cs-136	116	6.5000	3.8416E-06	9.1732E+01	5.2617E-01	2.1255E-03	7.870E-01	9.960E-01	1.7713E-05	1.394E-05	1.764E-05
Cs-137	170	124.0000	7.3286E-05	5.1725E+01	6.9623E-01	7.8631E-02	7.870E-01	9.960E-01	6.5526E-04	5.157E-04	6.526E-04
Cs-138	1239	515.0000	3.0437E-04	3.1199E+00	9.7840E-01	3.3447E+00	7.870E-01	9.960E-01	2.7873E-02	2.194E-02	2.776E-02
I-131	190.00	0.0041	2.3936E-09	4.3932E+01	7.3526E-01	3.0312E-06	7.870E-01	9.960E-01	2.5260E-08	1.988E-08	2.516E-08
I-132	270.00	0.0062	3.6820E-09	2.6420E+01	8.3115E-01	7.4903E-06	7.870E-01	9.960E-01	6.2419E-08	4.912E-08	6.217E-08
I-133	440.00	0.0725	4.2849E-08	1.3206E+01	9.1170E-01	1.5582E-04	7.870E-01	9.960E-01	1.2985E-06	1.022E-06	1.293E-06
I-134	460.00	0.0095	5.6383E-09	1.2405E+01	9.1683E-01	2.1556E-05	7.870E-01	9.960E-01	1.7963E-07	1.414E-07	1.789E-07
I-135	530.00	0.0083	4.9054E-09	1.0168E+01	9.3130E-01	2.1949E-05	7.870E-01	9.960E-01	1.8291E-07	1.439E-07	1.822E-07
									Total SDE	**7.151E-02**	**9.050E-02**

MHA DDE worker Gamma Contribution

MHA									
1.2.External Occupational Dose to Worker								ON	OFF
Gamma Dose rate from the Cloud (DDE = Dγ)								DDE [rem]	DDE [rem]
			χ_0		Avg $\chi_{t\,w/V}$	Avg $\chi_{t\,w/L}$	Dose χ_0	Dose χ_V	Dose χ_L
Isotope	$E_{\gamma,\,avg}$ (MeV)	Release mC	χ [Ci/m^3]	Dγ [rads/s]	Vent factor	Leak factor	300s [rads]	300s [rads]	300s [rads]
Kr-83m	0.00939	0.465	2.748E-07	1.308E-09	7.870E-01	9.960E-01	3.925E-07	3.089E-07	3.909E-07
Kr-85m	0.15118	1.076	6.359E-07	4.874E-08	7.870E-01	9.960E-01	1.462E-05	1.151E-05	1.456E-05
Kr-85	0.51400	0.018	1.064E-08	2.772E-09	7.870E-01	9.960E-01	8.317E-07	6.545E-07	8.284E-07
Kr-87	0.40256	2.070	1.223E-06	2.497E-07	7.870E-01	9.960E-01	7.491E-05	5.895E-05	7.461E-05
Kr-88	2.39210	2.959	1.749E-06	2.121E-06	7.870E-01	9.960E-01	6.363E-04	5.008E-04	6.337E-04
Kr-89	0.22090	3.638	2.150E-06	2.408E-07	7.870E-01	9.960E-01	7.224E-05	5.685E-05	7.195E-05
Kr-90	1.11870	4.133	2.443E-06	1.385E-06	7.870E-01	9.960E-01	4.156E-04	3.271E-04	4.140E-04
Xe-133n	0.03304	0.146	8.629E-08	1.446E-09	7.870E-01	9.960E-01	4.337E-07	3.413E-07	4.319E-07
Xe-133	0.02330	8.516	5.033E-06	5.946E-08	7.870E-01	9.960E-01	1.784E-05	1.404E-05	1.777E-05
Xe-135n	0.42128	2.243	1.326E-06	2.831E-07	7.870E-01	9.960E-01	8.494E-05	6.685E-05	8.460E-05
Xe-135	0.25466	3.844	2.272E-06	2.933E-07	7.870E-01	9.960E-01	8.800E-05	6.925E-05	8.765E-05
Sr-89	0.00010	0.2500	1.478E-07	7.491E-12	7.870E-01	9.960E-01	2.247E-09	1.769E-09	2.238E-09
Sr-91	0.62900	323.00	1.909E-04	6.088E-05	7.870E-01	9.960E-01	1.826E-02	1.437E-02	1.819E-02
Sr-92	1.29200	365.50	2.160E-04	1.415E-04	7.870E-01	9.960E-01	4.245E-02	3.341E-02	4.228E-02
Sr-93	1.66000	414.50	2.450E-04	2.062E-04	7.870E-01	9.960E-01	6.185E-02	4.868E-02	6.161E-02
Cs-134m	0.01792	0.5000	2.955E-07	2.685E-09	7.870E-01	9.960E-01	8.054E-07	6.339E-07	8.022E-07
Cs-134	1.39800	0.8000	4.728E-07	3.351E-07	7.870E-01	9.960E-01	1.005E-04	7.912E-05	1.001E-04
Cs-136	1.79500	6.5000	3.842E-06	3.496E-06	7.870E-01	9.960E-01	1.049E-03	8.254E-04	1.045E-03
Cs-137	0.59510	124.00	7.329E-05	2.211E-05	7.870E-01	9.960E-01	6.633E-03	5.221E-03	6.607E-03
Cs-138	1.04100	515.00	3.044E-04	1.606E-04	7.870E-01	9.960E-01	4.819E-02	3.793E-02	4.800E-02
				DDE =			1.799E-01	1.416E-01	1.792E-01

MHA SDE worker Beta contribution

MHA

1.2.External Occupational Dose to Worker	Shallow Dose Equivalent SDE at 7 mg/cm^2									ON	OFF
Beta Dose rate from the Cloud (SDE = D_{β})	$D_{\beta} = 2.45 \times E\text{-}7\ C\ E_{avg}\ e^{-\mu \times 0.007}$ mGy/hr									SDE rem	SDE rem
		release	χ_0				Avg $\chi_{t\ w/V}$	Avg $\chi_{t\ w/L}$	Dose χ_0	Dose χ_v	Dose χ_L
Isotope	$E_{\beta,\ avg}$ (keV)	mCi	χ [Ci/m^3]	$\mu_{\beta,t}$	$e^{-\mu\beta,t \times 0.007}$	D_{β} [mGy/hr]	Vent factor	Leak factor	300s [rads]	300s [rads]	300s [rads]
Kr-85m	230	1.0760	6.3593E-07	3.3279E+01	7.9219E-01	1.0504E-03	7.870E-01	9.960E-01	8.7530E-06	6.889E-06	8.718E-06
Kr-85	228	0.0180	1.0638E-08	3.3702E+01	7.8985E-01	1.7367E-05	7.870E-01	9.960E-01	1.4472E-07	1.139E-07	1.441E-07
Kr-87	1329	2.0700	1.2234E-06	2.8316E+00	9.8037E-01	1.4450E-02	7.870E-01	9.960E-01	1.2041E-04	9.477E-05	1.199E-04
Kr-88	366	2.9590	1.7488E-06	1.7129E+01	8.8701E-01	5.1466E-03	7.870E-01	9.960E-01	4.2888E-05	3.375E-05	4.272E-05
Kr-89	1650	3.6380	2.1501E-06	2.1001E+00	9.8541E-01	3.1691E-02	7.870E-01	9.960E-01	2.6409E-04	2.078E-04	2.630E-04
Kr-90	800	4.1330	2.4427E-06	5.7229E+00	9.6073E-01	1.7019E-02	7.870E-01	9.960E-01	1.4182E-04	1.116E-04	1.413E-04
Xe-133	416	8.5160	5.0331E-06	1.4293E+01	9.0479E-01	1.7173E-02	7.870E-01	9.960E-01	1.4311E-04	1.126E-04	1.425E-04
Xe-135m	100	2.2430	1.3257E-06	1.1532E+02	4.4608E-01	5.3605E-04	7.870E-01	9.960E-01	4.4671E-06	3.516E-06	4.449E-06
Xe-135	302	3.8440	2.2719E-06	2.2510E+01	8.5422E-01	5.3128E-03	7.870E-01	9.960E-01	4.4274E-05	3.484E-05	4.410E-05
Sr-89	584	0.2500	1.4775E-07	8.8761E+00	9.3976E-01	7.3508E-04	7.870E-01	9.960E-01	6.1257E-06	4.821E-06	6.101E-06
Sr-91	1354	323.0000	1.9090E-04	2.7595E+00	9.8087E-01	2.2983E+00	7.870E-01	9.960E-01	1.9152E-02	1.507E-02	1.908E-02
Sr-92	1521	365.5000	2.1602E-04	2.3499E+00	9.8369E-01	2.9298E+00	7.870E-01	9.960E-01	2.4415E-02	1.921E-02	2.432E-02
Sr-93	1000	414.5000	2.4498E-04	4.1980E+00	9.7104E-01	2.1564E+00	7.870E-01	9.960E-01	1.7970E-02	1.414E-02	1.790E-02
Cs-134	156	0.8000	4.7281E-07	5.8735E+01	6.6289E-01	4.4322E-04	7.870E-01	9.960E-01	3.6935E-06	2.907E-06	3.679E-06
Cs-136	116	6.5000	3.8416E-06	9.1732E+01	5.2617E-01	2.1255E-03	7.870E-01	9.960E-01	1.7713E-05	1.394E-05	1.764E-05
Cs-137	170	124.0000	7.3286E-05	5.1725E+01	6.9623E-01	7.8631E-02	7.870E-01	9.960E-01	6.5526E-04	5.157E-04	6.526E-04
Cs-138	1239	515.0000	3.0437E-04	3.1199E+00	9.7840E-01	3.3447E+00	7.870E-01	9.960E-01	2.7873E-02	2.194E-02	2.776E-02
I-131	190.00	0.0041	2.3936E-09	4.3932E+01	7.3526E-01	3.0312E-06	7.870E-01	9.960E-01	2.5260E-08	1.988E-08	2.516E-08
I-132	270.00	0.0062	3.6820E-09	2.6420E+01	8.3115E-01	7.4903E-06	7.870E-01	9.960E-01	6.2419E-08	4.912E-08	6.217E-08
I-133	440.00	0.0725	4.2849E-08	1.3206E+01	9.1170E-01	1.5582E-04	7.870E-01	9.960E-01	1.2985E-06	1.022E-06	1.293E-06
I-134	460.00	0.0095	5.6383E-09	1.2405E+01	9.1683E-01	2.1556E-05	7.870E-01	9.960E-01	1.7963E-07	1.414E-07	1.789E-07
I-135	530.00	0.0083	4.9054E-09	1.0168E+01	9.3130E-01	2.1949E-05	7.870E-01	9.960E-01	1.8291E-07	1.439E-07	1.822E-07
									Total SDE	**7.151E-02**	**9.050E-02**

Max dose to public (nearest residence) ventilation ON = 28.6 µrem
Max dose to public (nearest residence) ventilation OFF = 39.4 µrem

Data
Pasquill Atmospheric Stability classes and associated values

Stability Class factors for 175, 200, and 300 meters downwind on the center line

			σ_y [m]					σ_z [m]			pi	wind speed	eff height
(x,0) [m]	A	B	C	E	F	A	B	C	E	F	π	µ [m/s]	H [m]
175	40	27.5	20	10	7	28	18	4	5	2.5	3.14	2	7.3255
200	45	30	22.5	12.5	8	30	20	15	5.5	3	3.14	2	7.3255
300	70	46.5	35	18	13	55	30	22.5	8.5	4.7	3.14	2	7.3255

	[1/µσσπ]					$e^{-[1/2\ (H/\sigma)^2]}$				
(x,0) [m]	A	B	C	E	F	A	B	C	E	F
175	1.4217E-04	3.2169E-04	1.9904E-03	6.3694E-03	9.0992E-03	9.6636E-01	9.2052E-01	1.8694E-01	3.4189E-01	1.3663E-02
200	1.1795E-04	2.6539E-04	4.7181E-04	4.2463E-03	6.6348E-03	9.7063E-01	9.3512E-01	8.8758E-01	4.1189E-01	5.0728E-02
300	4.1360E-05	1.1415E-04	2.0220E-04	1.8822E-03	2.6061E-03	9.9117E-01	9.7063E-01	9.4838E-01	6.8979E-01	2.9682E-01

	$\chi/Q\ [s/m^3] = [1/\mu\sigma\sigma\pi] \times e^{-[1/2\ (H/\sigma)^2]}$				
(x,0) [m]	A	B	C	E	F
175	1.3739E-04	2.9612E-04	3.7209E-04	2.1777E-03	1.2433E-04
200	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
300	4.0995E-05	1.1079E-04	1.9177E-04	1.2983E-03	7.7355E-04

Data
Max Concentration Plume Data Ventilation ON nearest Residence Part 1

Ventilation ON Max Concentration distance 200 m

MHA data	Plume N 200 m		Nearest Residence				A 200	B 200	C 200	E 200	F 200
Nuclides	$f_v\ [m^3/s]$	$f_{L(5\%)}\ [m^3/s]$	A [Ci]	C_0 [Ci/m3]	Q_v [Ci/s]	$Q_{L(5\%)}$ [Ci/s]	$\chi/Q\ [s/m^3]$	$\chi/Q\ [s/m^3]$	$\chi/Q\ [s/m^3]$	$\chi/Q\ [s/m^3]$	$\chi/Q\ [s/m^3]$
Kr-83m	2.83	0.0235	4.6500E-04	2.7482E-07	7.7775E-07	6.4583E-09	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
Kr-85m	2.83	0.0235	1.0760E-03	6.3593E-07	1.7997E-06	1.4944E-08	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
Kr-85	2.83	0.0235	1.8000E-05	1.0638E-08	3.0106E-08	2.5000E-10	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
Kr-87	2.83	0.0235	2.0700E-03	1.2234E-06	3.4622E-06	2.8750E-08	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
Kr-88	2.83	0.0235	2.9590E-03	1.7488E-06	4.9492E-06	4.1097E-08	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
Xe-133m	2.83	0.0235	1.4600E-04	8.6288E-08	2.4420E-07	2.0278E-09	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
Xe-133	2.83	0.0235	8.5160E-03	5.0331E-06	1.4244E-05	1.1828E-07	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
Xe-135m	2.83	0.0235	2.2430E-03	1.3257E-06	3.7516E-06	3.1153E-08	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
Xe-135	2.83	0.0235	3.8440E-03	2.2719E-06	6.4294E-06	5.3389E-08	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04

							A 200	B 200	C 200	E 200	F 200
Nuclides	$f_v\ [m^3/s]$	$f_{L(5\%)}\ [m^3/s]$	A [Ci]	C_0 [Ci/m3]	Q_v [Ci/s]	$Q_{L(5\%)}$ [Ci/s]	$\chi/Q\ [s/m^3]$	$\chi/Q\ [s/m^3]$	$\chi/Q\ [s/m^3]$	$\chi/Q\ [s/m^3]$	$\chi/Q\ [s/m^3]$
I-131	2.83	0.0235	4.0500E-03	2.3936E-06	6.7739E-06	1.5919E-07	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
I-132	2.83	0.0235	6.2300E-03	3.6820E-06	1.0420E-05	2.4487E-07	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
I-133	2.83	0.0235	7.2500E-02	4.2849E-05	1.2126E-04	2.8497E-06	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
I-134	2.83	0.0235	9.5400E-03	5.6383E-06	1.5956E-05	3.7498E-07	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04
I-135	2.83	0.0235	8.3000E-03	4.9054E-06	1.3882E-05	3.2624E-07	1.1449E-04	2.4817E-04	4.1877E-04	1.7490E-03	3.3657E-04

Data

Max Concentration Plume Data Ventilation ON nearest Residence Part 2

A 200	B 200	C 200	E 200	F 200		A 200	B 200	C 200	E 200	F 200
X_v [Ci/m^3]	X_v [Ci/m^3]	X_v [Ci/m^3]	X_v [Ci/m^3]	X_v [Ci/m^3]	[rem/hr/Ci/	DDE [rem]	DDE [rem]	DDE [rem]	DDE [rem]	DDE [rem]
8.9043E-11	1.9302E-10	3.2570E-10	1.3603E-09	2.6177E-10	3.2375E-02	2.8828E-12	6.2489E-12	1.0544E-11	4.4040E-11	8.4747E-12
2.0604E-10	4.4664E-10	7.5366E-10	3.1477E-09	6.0573E-10	9.0958E+01	1.8741E-08	4.0625E-08	6.8552E-08	2.8631E-07	5.5096E-08
3.4468E-12	7.4716E-12	1.2608E-11	5.2657E-11	1.0133E-11	3.3917E+00	1.1690E-11	2.5341E-11	4.2761E-11	1.7859E-10	3.4368E-11
3.9638E-10	8.5924E-10	1.4499E-09	6.0555E-09	1.1653E-09	5.2417E+02	2.0777E-07	4.5038E-07	7.5998E-07	3.1741E-06	6.1081E-07
5.6662E-10	1.2283E-09	2.0726E-09	8.6562E-09	1.6657E-09	1.2950E+03	7.3377E-07	1.5906E-06	2.6840E-06	1.1210E-05	2.1571E-06
2.7957E-11	6.0603E-11	1.0226E-10	4.2710E-10	8.2190E-11	1.6958E+01	4.7411E-10	1.0277E-09	1.7342E-09	7.2430E-09	1.3938E-09
1.6307E-09	3.5349E-09	5.9648E-09	2.4912E-08	4.7940E-09	1.8500E+01	3.0168E-08	6.5396E-08	1.1035E-07	4.6088E-07	8.8689E-08
4.2951E-10	9.3105E-10	1.5711E-09	6.5616E-09	1.2627E-09	2.4667E+02	1.0595E-07	2.2966E-07	3.8753E-07	1.6185E-06	3.1146E-07
7.3609E-10	1.5956E-09	2.6924E-09	1.1245E-08	2.1640E-09	1.4800E+02	1.0894E-07	2.3615E-07	3.9848E-07	1.6643E-06	3.2026E-07
					Total DDE	**1.2058E-06**	**2.6139E-06**	**4.4106E-06**	**1.8421E-05**	**3.5449E-06**

				CED		A 200	B 200	C 200	E 200	F 200
B_r [m3/s]				DCF [rem/Ci]		CEDE [rem]	CEDE [rem]	CEDE [rem]	CEDE [rem]	CEDE [rem]
3.33E-04				7.4000E+02		3.4278E-09	7.4304E-09	1.2538E-08	5.2366E-08	1.0077E-08
3.33E-04				4.0700E+02		2.9001E-09	6.2864E-09	1.0608E-08	4.4304E-08	8.5256E-09
3.33E-04				7.7700E+03		6.4429E-07	1.3966E-06	2.3567E-06	9.8428E-06	1.8941E-06
3.33E-04				2.9230E+02		3.1893E-09	6.9135E-09	1.1666E-08	4.8723E-08	9.3761E-09
3.33E-04				1.7020E+03		1.6157E-08	3.5024E-08	5.9099E-08	2.4683E-07	4.7499E-08
					Total CEDE	**6.6997E-07**	**1.4523E-06**	**2.4506E-06**	**1.0235E-05**	**1.9696E-06**
					TEDE	**1.8758E-06**	**4.0661E-06**	**6.8612E-06**	**2.8656E-05**	**5.5145E-06**

Data

Max Concentration Plume Data Ventilation OFF nearest Residence Part 1

MHA Plume Model 200 m Nearest Residence Ground Release Ventilation OFF (leakage)

MHA data	**Plume M**	**200 m**	**Nearest Residence**			A 200	B 200	C 200	E 200
Nuclides	$_{(5\%)}$ [m^3/	**A [Ci]**	**C_0 [Ci/m3]**	**$Q_{L(5\%)}$ [Ci/s]**	**χ/Q [s/m^3]**	**χ/Q [s/m^3]**	**χ/Q [s/m^3]**	**χ/Q [s/m^3]**	**χ/Q [s/m^3]**
Kr-83m	0.0235	4.6500E-04	2.7482E-07	6.4583E-09	0.000118	0.0002654	0.0004718	0.0042463	0.0066348
Kr-85m	0.0235	1.0760E-03	6.3593E-07	1.4944E-08	0.000118	0.0002654	0.0004718	0.0042463	0.0066348
Kr-85	0.0235	1.8000E-05	1.0638E-08	2.5000E-10	0.000118	0.0002654	0.0004718	0.0042463	0.0066348
Kr-87	0.0235	2.0700E-03	1.2234E-06	2.8750E-08	0.000118	0.0002654	0.0004718	0.0042463	0.0066348
Kr-88	0.0235	2.9590E-03	1.7488E-06	4.1097E-08	0.000118	0.0002654	0.0004718	0.0042463	0.0066348
Xe-133m	0.0235	1.4600E-04	8.6288E-08	2.0278E-09	0.000118	0.0002654	0.0004718	0.0042463	0.0066348
Xe-133	0.0235	8.5160E-03	5.0331E-06	1.1828E-07	0.000118	0.0002654	0.0004718	0.0042463	0.0066348
Xe-135m	0.0235	2.2430E-03	1.3257E-06	3.1153E-08	0.000118	0.0002654	0.0004718	0.0042463	0.0066348
Xe-135	0.0235	3.8440E-03	2.2719E-06	5.3389E-08	0.000118	0.0002654	0.0004718	0.0042463	0.0066348

					A 200	B 200	C 200	E 200	F 200
Nuclides	$_{(5\%)}$ [m^3/	**A [Ci]**	**C_0 [Ci/m3]**	**$Q_{L(5\%)}$ [Ci/s]**	**χ/Q [s/m^3]**	**χ/Q [s/m^3]**	**χ/Q [s/m^3]**	**χ/Q [s/m^3]**	**χ/Q [s/m^3]**
I-131	0.0235	4.0500E-03	2.3936E-06	5.6250E-08	1.1795E-04	2.6539E-04	4.7181E-04	4.2463E-03	6.6348E-03
I-132	0.0235	6.2300E-03	3.6820E-06	8.6528E-08	1.1795E-04	2.6539E-04	4.7181E-04	4.2463E-03	6.6348E-03
I-133	0.0235	7.2500E-02	4.2849E-05	1.0069E-06	1.1795E-04	2.6539E-04	4.7181E-04	4.2463E-03	6.6348E-03
I-134	0.0235	9.5400E-03	5.6383E-06	1.3250E-07	1.1795E-04	2.6539E-04	4.7181E-04	4.2463E-03	6.6348E-03
I-135	0.0235	8.3000E-03	4.9054E-06	1.1528E-07	1.1795E-04	2.6539E-04	4.7181E-04	4.2463E-03	6.6348E-03

Data

Max Concentration Plume Data Ventilation OFF nearest Residence Part 2

F 200	A 200	B 200	C 200	E 200	F 200	A 200	B 200	C 200	E 200	F 200
XL [Ci/m^3]	XL [Ci/m^3]	XL [Ci/m^3]	XL [Ci/m^3]	XL [Ci/m^3]	F [rem/hr/Ci/r	DDE [rem]	DDE [rem]	DDE [rem]	DDE [rem]	DDE [rem]
7.6178E-13	1.7140E-12	3.0471E-12	2.7424E-11	4.2850E-11	3.2375E-02	2.4662E-14	5.5491E-14	9.8650E-14	8.8785E-13	1.3873E-12
1.7627E-12	3.9661E-12	7.0509E-12	6.3458E-11	9.9154E-11	9.0958E+01	1.6034E-10	3.6075E-10	6.4134E-10	5.7721E-09	9.0189E-09
2.9488E-14	6.6348E-14	1.1795E-13	1.0616E-12	1.6587E-12	3.3917E+00	1.0001E-13	2.2503E-13	4.0006E-13	3.6005E-12	5.6258E-12
3.3911E-12	7.6300E-12	1.3565E-11	1.2208E-10	1.9075E-10	5.2417E+02	1.7775E-09	3.9994E-09	7.1101E-09	6.3991E-08	9.9985E-08
4.8475E-12	1.0907E-11	1.9390E-11	1.7451E-10	2.7267E-10	1.2950E+03	6.2775E-09	1.4124E-08	2.5110E-08	2.2599E-07	3.5311E-07
2.3918E-13	5.3816E-13	9.5672E-13	8.6105E-12	1.3454E-11	1.6958E+01	4.0561E-12	9.1263E-12	1.6224E-11	1.4602E-10	2.2816E-10
1.3951E-11	3.1390E-11	5.5805E-11	5.0224E-10	7.8475E-10	1.8500E+01	2.5810E-10	5.8072E-10	1.0324E-09	9.2915E-09	1.4518E-08
3.6745E-12	8.2677E-12	1.4698E-11	1.3228E-10	2.0669E-10	2.4667E+02	9.0639E-10	2.0394E-09	3.6255E-09	3.2630E-08	5.0984E-08
6.2973E-12	1.4169E-11	2.5189E-11	2.2670E-10	3.5423E-10	1.4800E+02	9.3201E-10	2.0970E-09	3.7280E-09	3.3552E-08	5.2425E-08
					Total DDE	**1.0316E-08**	**2.3211E-08**	**4.1264E-08**	**3.7138E-07**	**5.8028E-07**

				CED		A 200	B 200	C 200	E 200	F 200
B_r [m3/s]				DCF [rem/Ci]		CEDE [rem]	CEDE [rem]	CEDE [rem]	CEDE [rem]	CEDE [rem]
3.33E-04				7.4000E+02		3.5315E-09	7.9459E-09	1.4126E-08	1.2713E-07	1.9865E-07
3.33E-04				4.0700E+02		2.9878E-09	6.7226E-09	1.1951E-08	1.0756E-07	1.6806E-07
3.33E-04				7.7700E+03		6.6379E-07	1.4935E-06	2.6552E-06	2.3896E-05	3.7338E-05
3.33E-04				2.9230E+02		3.2859E-09	7.3932E-09	1.3143E-08	1.1829E-07	1.8483E-07
3.33E-04				1.7020E+03		1.6646E-08	3.7453E-08	6.6584E-08	5.9926E-07	9.3634E-07
					Total CEDE	**6.9024E-07**	**1.5530E-06**	**2.7610E-06**	**2.4849E-05**	**3.8826E-05**
					TEDE [rem]	**7.0056E-07**	**1.5763E-06**	**2.8022E-06**	**2.5220E-05**	**3.9406E-05**

Max dose rate to public at door to reactor ventilation ON = 1.22 mrem/hr
Max dose rate to public at door to reactor ventilation OFF = 25.86 mrem/hr

Data
MHA Public at the Door Gamma Contribution Ventilation ON and OFF
Ventilation ON/OFF

Gamma Dose rate from the volume cloud inside the reactor at door

Nuclides	Gamma Constant [rem/hr/Ci/m2]	A [Ci]	Time [hr]	half-life [hr]	Avg_v [Ci/m3] ON	linear energy absorption coefficient	Avg_v [Ci/m3] OFF	$Dose_v$ ON [rem]	$Dose_L$ OFF [rem]
Kr-83m	0.11873	0.00047	1	1.83	2.28598E-07	3.01502E-05	2.28776E-07	5.90721E-08	1.08185E-07
Kr-85m	0.16013	0.00108	1	4.48	5.8871E-07	3.24794E-05	5.89185E-07	2.05174E-07	9.19869E-07
Kr-85	0.00156	1.8E-05	1	93907.2	1.06294E-08	3.84318E-05	1.06382E-08	3.60893E-11	9.14396E-07
Kr-87	0.43253	0.00207	1	1.271666667	9.42465E-07	3.83024E-05	9.43176E-07	8.87213E-07	1.12909E-06
Kr-88	1.02453	0.00296	1	0.047333333	1.19434E-07	3.02796E-05	1.19448E-07	2.66319E-07	1.26074E-08
Xe-133m	0.11225	0.00015	1	52.512	8.565E-08	3.01502E-05	8.57209E-08	2.09249E-08	1.09886E-06
Xe-133	0.10297	0.00852	1	125.88	5.01508E-06	3.01502E-05	5.01923E-06	1.12392E-06	0.000141331
Xe-135m	0.32008	0.00224	1	0.254833333	4.55118E-07	3.83024E-05	4.55342E-07	3.17051E-07	8.08361E-08
Xe-135	0.18947	0.00384	1	9.09	2.18562E-06	3.59732E-05	2.18741E-06	9.01286E-07	8.19821E-06
I-131	0.28293	0.00405	1	192	2.38731E-06	3.83024E-05	2.38929E-06	1.47006E-06	0.000281454
I-132	1.4274	0.00623	1	2.3	3.17656E-06	3.79142E-05	3.17906E-06	9.86846E-06	2.27148E-05
I-133	0.4088	0.0725	1	20.8	4.21077E-05	3.83024E-05	4.21425E-05	3.74645E-05	0.000779608
I-134	1.5728	0.00954	1	0.876666667	3.89429E-06	3.79142E-05	3.8971E-06	1.33306E-05	1.16949E-05
I-135	0.8609	0.0083	1	6.61	4.65322E-06	3.73966E-05	4.65702E-06	8.71874E-06	5.76718E-05
Sr-89	0.00008158	0.00025	1	1212	1.47712E-07	3.01502E-05	1.47712E-07	2.62269E-11	1.4767E-07
Sr-91	0.41366	0.323	1	9.5	0.000184102	3.83024E-05	0.000184102	0.000165748	0.000177547
Sr-92	0.72002	0.3655	1	2.71	0.000190608	3.46792E-05	0.000190608	0.000298698	0.000168188
Sr-93	1.35605	0.4145	1	0.13	4.57327E-05	0.00003235	4.57327E-05	0.000134974	8.53748E-06
Cs-134m	0.070448	0.0005	1	2.9	2.62852E-07	3.01502E-05	2.62852E-07	4.03022E-08	2.33805E-07
Cs-134	0.99937	0.0008	1	18063	4.72804E-07	0.000033644	4.72804E-07	1.02838E-06	4.72795E-07
Cs-136	1.34384	0.0065	1	314.4	3.83738E-06	0.000031056	3.83738E-06	1.12236E-05	3.83315E-06
Cs-137	0.38184	0.124	1	262800	7.3286E-05	3.83024E-05	7.3286E-05	6.09044E-05	7.32859E-05
Cs-138	1.26614	0.515	1	0.54	0.00017145	0.000036232	0.00017145	0.000472463	9.65762E-05
							Sub Total	**0.001219713**	**0.001835758**

Data

MHA Public at the door Beta Contribution ON and OFF

Ventilation ON/OFF

Beta Dose rate from the volume cloud inside the reactor at door			
Dβ = 1.1 x E+3 C Eavg [mrad/hr]			
			1 hour exp
μ□,t air	$e^{-\mu□,t}$	Dsurf [mrad/hr]	Dsurf [mrad]
2.8994E+01	0.0000E+00	0.0000E+00	0.0000E+00
2.9371E+01	0.0000E+00	0.0000E+00	0.0000E+00
2.3374E+00	3.6114E-48	4.9925E-45	4.9925E-45
1.4708E+01	2.9816E-299	1.6226E-296	1.6226E-296
1.7223E+00	1.1015E-35	3.3227E-32	3.3227E-32
4.7975E+00	4.2128E-98	6.9996E-95	6.9996E-95
1.2224E+01	7.6822E-249	1.3676E-245	1.3676E-245
1.0325E+02	0.0000E+00	0.0000E+00	0.0000E+00
1.9444E+01	0.0000E+00	0.0000E+00	0.0000E+00
7.5127E+00	3.2615E-153	2.3928E-151	2.3928E-151
2.2767E+00	6.1711E-47	1.3562E-41	1.3562E-41
1.9319E+00	6.1349E-40	1.7138E-34	1.7138E-34
3.4953E+00	1.1331E-71	2.3601E-66	2.3601E-66
5.1813E+01	0.0000E+00	0.0000E+00	0.0000E+00
8.1715E+01	0.0000E+00	0.0000E+00	0.0000E+00
4.5502E+01	0.0000E+00	0.0000E+00	0.0000E+00
2.5809E+00	4.1247E-53	1.3226E-47	1.3226E-47
	Subtotal	**3.3398E-32**	**3.3398E-32**

Data

MHA Public at the door Beta Submersion Contribution Ventilation OFF

Ventilation OFF						
Beta submersion Dose at door						
Isotope	**C0[Ci/m3]**	**Cavg [Ci/m3]**	**5% of Cavg [Ci/m3]**	**DCF [rem/hr/Ci/m3]**	**Eavg [Mev]**	**rem/hr**
Kr-85m	6.35934E-07	5.29386E-07	2.6469E-08	0.032375	0.227	1.38196E-09
Kr-85	1.06383E-08	9.85633E-09	4.9282E-10	90.95833333	0.251	2.84503E-11
Kr-87	1.2234E-06	1.2234E-06	6.117E-08	3.391666667	1.27	1.78678E-08
Kr-88	1.74882E-06	1.34825E-06	6.7412E-08	524.1666667	0.28	4.34136E-09
Kr-89	2.15012E-06	1.46857E-07	7.3429E-09	1295	1.4	2.36441E-09
Kr-90	2.44267E-06	2.42662E-06	1.2133E-07	16.95833333	0.8	2.23249E-08
Xe-133	5.0331E-06	5.01927E-06	2.5096E-07	18.5	0.1	5.77216E-09
Xe-135m	1.32565E-06	4.55344E-07	2.2767E-08	246.6666667	0.1	5.23645E-10
Xe-135	2.27187E-06	2.18743E-06	1.0937E-07	148	0.28	7.04351E-09
					Subtotal	**6.16482E-08**

Data
MHA Public at Door Vent OFF
Ventilation OFF

Gamma submersion dose at door		
what leaks out 5% of OFF C	Gamma submersion dose 1hr OFF rads	Eγ, avg (MeV)
1.14E-08	1.96045E-07	0.00939
2.95E-08	8.12881E-06	0.15118
5.32E-10	4.99012E-07	0.514
4.72E-08	3.465E-05	0.40256
5.97E-09	2.60758E-05	2.3921
4.29E-09	1.72808E-06	0.2209
2.51E-07	0.000512426	1.1187
2.28E-08	1.37304E-06	0.033042
1.09E-07	4.65122E-06	0.0233
1.19E-07	8.28576E-05	0.38
1.59E-07	0.000193511	0.667
2.11E-06	0.002192175	0.57
1.95E-07	0.000257134	0.723
2.33E-07	0.000359549	0.846
Subtotal	**0.003674956**	

Data
MHA Public at Door Ventilation OFF
Ventilation OFF

Internal dose public at the door			
Br [m^3/s]	t_{evac} [s]	DCF [rem/Ci]	Dp_L_{3600s} [rem]
0.000333	3600	740	0.000105978
0.000333	3600	407	7.75551E-05
0.000333	3600	7770	0.019627172
0.000333	3600	292.3	6.82789E-05
0.000333	3600	1702	0.000475099
		Subtotal	**0.020354083**

Normal Operations Summary

The occupational dose to the worker with ventilation OFF assumes that 100% of the Ar-41 readily diffuses out of the water and into the reactor volume. Air and Water sampling during operation at full power has shown that the majority of the Ar-41 remains in the pool and is not diffused to the atmosphere, therefore a factor of at least ¼ can be applied to the activity in the reactor bay due to Ar-41 production in the pool. For 2000 hours of operation the dose to workers is:

Occupational dose to workers ventilation ON = 19.6 mrem
Occupational dose to workers ventilation OFF = 289 mrem

Calculation:

The Argon-41 production rate is stated as 0.1 Ci/30 MWhrs

For a member of the public located on the lower level outside the double doors on the south side of the reactor in the case of ventilation ON, the only source of exposure to the individual would be from shine inside the reactor bay. In the case of ventilation OFF the individual could receive an exposure from leakage out of the reactor and from any shine from Ar-41 production inside the reactor.

Annual dose to the public at the door to the reactor, ventilation ON = 3.71 mrem

Annual dose to the public at the door to the reactor, ventilation OFF will be determined by air sampling and quantification of Ar-41 over the pool and in the reactor bay volume, with subsequent dose calculation. The reactor is currently not operating in order to install new fission chamber elements. Upon start up Ar-41 will be collected by grab sample and measured through HpGe and NaI gamma spectroscopy.

Doses to the public located at the nearest residence from elevated releases (ventilation ON) and from a ground release (ventilation OFF) is calculated using the Gaussian Plume model.

Max dose to public (nearest residence) ventilation ON = 6.33 mrem
Max dose to public (nearest residence) ventilation OFF = 0.200 mrem