CALCULATION OF ARGON-41 CONCENTRATIONS FOR THE UNIVERSITY OF FLORIDA TRAINING REACTOR USING ATMOSPHERIC DISPERSION MODELING CODES: STAC2.1 AND CALPUFF

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ABSTRACT

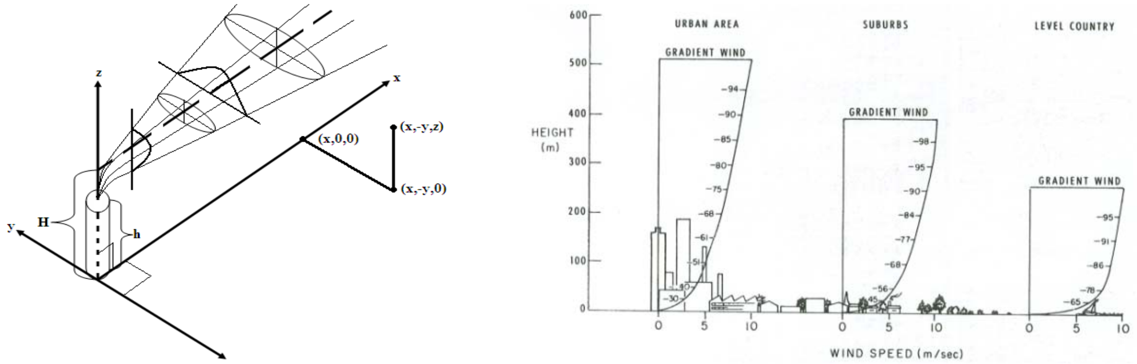
Atmospheric plume dispersion modeling and meteorological data were applied to estimate downwind concentrations of Ar-41 exhausted during routine University of Florida Training Reactor (UFTR) operations. Two Gaussian-based concentration prediction codes were employed: STAC2.1 and CALPUFF. Gaussian plume atmospheric models are based on methods initially developed by Pasquill, Briggs, and Turner; these methodologies were adopted by the EPA, Federal Coordinator of Meteorology, and ASME.

Yearly maximum average predicted concentrations, dose rates, operational limits, dilution factors, and a stack height study were performed for routine UFTR operational parameters, with impact assessments assuming dedicated winds near campus buildings at full reactor power (100kW). Calculations were accomplished using STAC2.1, developed at UF, and for independent correlation, results were compared to those derived from CALPUFF, an established, detailed air pollution transport code. Results from both independent codes were quite consistent. Moreover, all work in this area was integral to the UFTR NRC re-licensing process.

1. Introduction

Atmospheric plume dispersion modeling, integrating atmospheric statistical dynamics, diffusion, and meteorological data may be applied to achieve an estimate of the downwind concentration of Ar-41 effluent released during steady state operation of the University of Florida Training Reactor (UFTR). The atmospheric modeling approach utilized to determine effluent levels is based on the methods constructed by Pasquill and further expounded upon by Briggs and Turner [1 – 4], with related methodologies applied in US Atomic Energy Commission studies [5]. We note that these methods have been adopted and used as a basis for methodologies adopted by the Environmental Protection Agency, Federal Coordinator of Meteorology, and the American Society for Mechanical Engineers [1, 4, 6, 7].

Wind direction and atmospheric conditions such as temperature, solar radiation, and wind speed distinctly affect the path of effluents dispersed from an exhaust stack [1 – 4, 8]. The specific time of day versus night conditions are important, due to environmental changes in the lapse rate from the combined effects of heating and cloud cover. These varying conditions, along with the accepted mathematical models, allow the concentration of Ar-41 to be conservatively estimated with a simple one-wind, Gaussian computer code employing proper model physics: STAC2 (Version 2.1) Build 1.5b (hereafter referred to as ‘STAC2.1’) [7]. Note that while wind speed and temperature specifically affect effluent concentration, wind direction simply determines the vector location along which the effluent flows. The basis of STAC2.1 is a Gaussian plume model. The Gaussian model, illustrated in Fig. 1 (a) , describes, in three-dimensions, the theoretical path of a plume emerging from the stack: straight downwind, horizontally, and vertically [4]. These directions correspond, respectively to a coordinate system along the x-axis (parallel to the wind vector), y-axis, and z-axis. Figure 1(a) illustrates the basic plume and plume centerline (bold, dashed line parallel to the x-axis). The "H" in the figure represents the effective stack height relative to the plume centerline, and "h" is the physical height of the stack. The profile of the plume is detailed with the elliptical and parabolic sketches to demonstrate three dimensional depths.



(a) (b)

Figure 1: (a) Coordinate System of Gaussian distributions straight downwind, horizontal, and vertical [4]; (b) Effect of Terrain Roughness on the General Wind Speed Profile [1]

In addition, frictional (drag) effects on wind speed can be approximated using a terrain category typical of the region where the atmospheric transport is occurring. For the University of Florida campus, the terrain is assumed to be urban with a flat landscape. The comparison between urban, suburban, and rural, to capture specific effects of different terrain on wind speed profiles, is shown in Fig. 1(b) [1, 4]. As surface roughness decreases, the depth of the affected atmospheric layer becomes more shallow, and the wind speed profile becomes steeper. The numbers reflected in the curves refer to normalized percentages of the wind gradient at various heights.

The UFTR, an Argonaut design, produces Ar-41 by neutron activation in the course of operations. This effluent is discharged from the air handling equipment from the exhaust stack adjacent to the reactor building. The limiting parameter for the operating duty cycle of the UFTR is the concentration of Ar-41; monthly concentration averages in uncontrolled spaces for Ar-41 must not exceed 1.00E-8 Ci/m^3 (note: 1 Ci/m^3 = 1μCi/mL), at 100% reactor power, per state and federal guidelines (10CFR20) [9, 10]. The UFTR is in close proximity to many building structures on the Florida campus, including the Ben Hill Griffin Football Stadium, other engineering departments, parking garages, and students' residence halls. The closest student residence hall, East Hall, is located approximately 190m west-southwest of the UFTR.

2. Calculation Theory Implemented in STAC2.1

The Ar-41 concentrations, emitted from the UFTR stack, are calculated based on standard ASME effluent diffusion equations and Pasquill stability classes determined from atmospheric conditions, which are cast as input parameters for STAC2.1 [1, 2, 4, 7]. The principal governing equation for the determination of down-wind ground concentration is given in Eq. (1), with variables cast as: concentration of effluent (Ar-41) released (χ) in Ci/m^3, release rate (Q) in Ci/s, effective stack height (h) in m, average wind speed (u_s) in m/s, horizontal standard dispersion coefficient ($\sigma_y = \sigma_y(x)$) as a function of (x) distance from the stack in meters, vertical dispersion coefficient ($\sigma_z = \sigma_z(x)$) as a function of distance from the stack in meters, and horizontal shift from the centerline (y) in m. As can be seen by inspection of Eq. (1), the maximum predicted ground (z=0) concentrations occur immediately downwind from the stack, where there is no horizontal shift (y = 0).

$$\chi(x,y,z) = \frac{Q}{\pi\sigma_y(x)\sigma_z(x)u}\exp\left\{-\left[\frac{h^2}{2\sigma_y(x)^2}+\frac{y^2}{2\sigma_z(x)^2}\right]\right\} \tag{1}$$

An “effective” stack height (h), in meters, is calculated, using a conservative buoyant plume estimate, and is the height of the plume centerline above the source accounting for the rise of the physical effluent discharged at the stack. The height of the plume centerline is computed by STAC2.1, while the height of the physical stack is an input parameter. The crosswind dispersion coefficients, σ_y and σ_z are determined by the atmospheric stability classes (“A” through “F”) and were originally created by Pasquill, where “A” is the most *unstable* condition, and “F” is the most *stable*.

Relative “stability” is determined by the amount of solar radiation, wind speed, outside temperature, relative lapse rate (0.65 ^{o}C/100m for the case of the UFTR), and the effluent release time of day (day or night) [1, 2]. Characteristically, “unstable” is considered warm and sunny (daytime), while “stable” is cool and overcast (nighttime). Table 1 describes, in general, the characteristics attributed to each class.

Table 1: Pasquill Weather Condition Categories [2]

Category	Time of day	Typical Conditions	Weather Descriptions	Wind m/s	Wind Direction – Stand. Dev.
A	Day	Extremely Unstable	Very Sunny Summer	1	+- 25 deg
B		Moderately Unstable	Sunny and Warm	2	+- 20 deg
C		Slightly Unstable	Average Daytime	5	+- 15 deg
D	Night	Neutral Stability	Overcast Day/Night	5	+- 10 deg
E		Slightly Stable	Average Nighttime	3	+- 5 deg
F		Moderately Stable	Clear Nighttime	2	+- 3 deg

In addition, with regard to the effluent (Ar-41), STAC 2.1 takes into account the half-life, density ratio to air, specific heat of the bulk effluent, and the molecular weight (for ppt-v determinations, if required). In addition, STAC2.1 accounts for general terrain altitude as a tunable parameter for density corrections.

3. Validation of STAC2.1 Results both “By-Hand” and using CALPUFF

The release rate, specific to the UFTR, was calculated to be 9.228 E-5 Ci/s (Q). The details of this release source term are depicted in Eq. (2) – (4) [1, 2, 4, 11-13]. Additional parameters in these equations, relative to the UFTR reactor, are: the undiluted release rate of Ar-41 from the reactor at 100kW (full power) (8.147 E-4 Ci/m^3), the total stack flow rate for Ar-41 from the core vent and dilution fan ($\dot{f}$) (15772 ft^3/min or 7.444 m^3/s), the dilution factor (Λ) from the dilution fan and core vent (dimensionless) (0.0152168), and the flow diluted release concentration at the top of the stack (ψ = 1.24E-5 Ci/m^3) [12, 13]. The fan flow rate value was determined as a result of the most recent service to the dilution fan. This dilution factor (Λ) takes into account that Ar-41 comes from the core (reactor) via the core vent, which is then dispersed by both the core vent and the dilution fan [12, 13].

$$\Lambda = \frac{\text{Core Vent Flow Rate } \frac{\text{ft}^3}{\text{min}}}{\dot{\text{f}} \frac{\text{ft}^3}{\text{min}}} \tag{2}$$

$$\psi \ \frac{\text{Ci}}{\text{m}^3} = 8.147\text{E-4} \ \frac{\text{Ci}}{\text{m}^3} * \Lambda \tag{3}$$

$$\text{Q} \ \frac{\text{Ci}}{\text{s}} = \psi \ \frac{\text{Ci}}{\text{m}^3} * \dot{\text{f}} \ \frac{\text{m}^3}{\text{s}} \tag{4}$$

In STAC2.1, the release rate was initially modeled assuming a unit source to calculate general maximum concentrations straight downwind from the stack. Final concentrations of Ar-41, for the UFTR, were calculated by multiplying these general concentrations by the specific release rate, 9.228E-5 Ci/s.

All calculations were verified, independently, manually, as shown in Table 1. Tabulated values for σ_y and σ_z, atmospheric conditions for Gainesville, Florida, and the stack height and release rate for the UFTR were applied to Eq. (1) for the manual calculation. Concentrations were compared for various distances from the UFTR versus those computed using STAC2.1 for the year between July 2004 and July 2005 assuming extremely unstable conditions.

In addition, we note that the temperature of the effluent was assumed to be the same as the average ambient temperature; 23.05°C. The average *daytime* wind azimuth direction for the year was from 167.11°, and the average ground wind speed was 2.42 m/s. As shown in the last row of Table 2, the differences in the concentrations determined via tabular "by-hand" values or STAC2.1 code runs were less than 3.61% within 500m, and less than 0.77% within 100m downwind of the stack. To explain the differences, the "by-hand" computations do not account for all of the physics (buoyant plume rise with temperature, decay at time of arrival, etc), and are less robust than conditions used in the STAC2.1 calculations [14].

Table 2: Urban Pasquill Class "A" Ground Level Concentration of Ar-41 Manual Calculation vs. STAC2.1 Results at Various Distances from the UFTR (July 2004 – 2005)

Distance from building (m)	50	100	500	Assumed
Effective height of effluent release (m)	12.3	12.3	12.3	[12]
Wind speed at the stack (m/s)	3.99	3.99	3.99	[12]
Sigma y (m)	10.97	21.89	107.35	[1, 4]
Sigma z (m)	10.00	20.00	100.00	
By Hand Concentration: (Ci/m^3) (Eq. 1)	3.15E-08	1.39E-08	6.81E-10	[1, 4]
STAC2.1 Multiplier: Release Rate is Unity	3.39E-04	1.50E-04	7.11E-06	Calculation
STAC2.1 Concentration: Multiplier * UFTR Release Rate (9.228E-5 Ci/m^3)	3.13E-08	1.38E-08	6.56E-10	Calculation
% Difference: STAC2.1 vs. Manual	-0.70%	-0.77%	-3.61%	Calculation

‘CALPUFF’ is an EPA approved California puff and slug atmospheric dispersion modeling program for accurate concentration and effluent spread prediction over complicated terrain [15]. Puffs are circular, Gaussian mappings of effluent concentrations, while slugs are elongations of these puffs using Lagrangian and Gaussian methods. Four CALPUFF models were created using summer weather conditions, details for the UFTR stack, Ar-41 characteristics, a flat, uniform terrain associated with Gainesville, FL, no “over water” effects, and using an urban wind model. The four studies included combinations of puff and slug models with two different wind extrapolation methods; power law and similarity methods. A STAC2.1model was created to match the average weather conditions, flat terrain, and urban model, as well as the UFTR and Ar-41 parameters used in CALPUFF, and then compared to each of the four cases. The results of this comparison are given in Tables 3 and 4.

Table 3: STAC 2.1 and CALPUFF/CALGROUP Comparison with a Puff Model

Models	Similarity Theory			Power Law		
	Maximum Conc. (Ci/m^3)	% Diff. in Conc.	Distance from Stack (m)	Maximum Conc. (Ci/m^3)	% Diff. in Conc.	Distance from Stack (m)
STAC2.1 (Maximum)	1.83E-08	30.71	103	1.83E-08	19.61	103
STAC2.1 (Same Distance as CALPUFF)	1.49E-08	6.43	79	1.49E-08	-2.61	79
CALPUFF/CALGROUP	1.40E-08	N/A	79	1.53E-08	N/A	79

Table 4: STAC 2.1 and CALPUFF/CALPGROUP Comparison with a Slug Model

Models	Similarity Theory			Power Law		
	Maximum Conc. (Ci/m^3)	% Diff. in Conc.	Distance from Stack (m)	Maximum Conc. (Ci/m^3)	% Diff. in Conc.	Distance from Stack (m)
STAC2.1 (Maximum)	1.83E-08	23.65	103	1.83E-08	18.83	103
STAC2.1 (Same Distance as CALPUFF)	1.49E-08	0.68	79	1.49E-08	-3.25	79
CALPUFF/CALGROUP	1.48E-08	N/A	79	1.54E-08	N/A	79

Maximum concentrations computed using STAC2.1 and CALPUFF software models were compared for each of the cases. It was found that the *relative distance* where the *maximum concentration occurred* was as much as 31% different between the two models. This distance of the maximum concentration was identical in all four CALPUFF models. The maximum concentration values differed from between ~19% and 31%, depending on whether a puff or slug model, or wind extrapolation power law or similarity theory was employed. STAC2.1 results most closely matched the slug, power law model, and in each case, the STAC2.1 results yielded the highest concentrations. Comparisons between concentrations for the same downwind distances differed between the codes by a range of only ~1% to 6 %. The best model relative to a comparison with STAC2.1 is the ‘CALGROUP slug and wind extrapolation power law model,’ which resulted in a percent difference of ~19%.

Overall, the amalgam of all of these results demonstrate that STAC2.1 yields a conservative and reasonable estimate for the effluent concentration of Ar-41 downwind from the stack, and can therefore be used in establishing Ar-41 concentrations for UFTR operations.

4. Calculations

STAC2.1 Concentration and Dose Results for the UFTR

STAC2.1 was used to calculate conservative concentrations. Remember that the highest daytime concentrations, closest to the stack, occur for Pasquill class "A," the most unstable condition. In addition, for class "C", while the concentrations are lower overall, the concentrations remain above the prescribed limit further from the stack. To ascertain the Ar-41 concentrations for the UFTR, while accounting for atmospheric influences, local weather condition measurements were acquired from the local conditions recorded daily by the UF Department of Physics Weather Station [2, 4]. The information located in Tables 5 and 6 are the average temperatures, wind directions, wind speeds, and Pasquill Classes attributed for the yearly period between July 2004 and July 2005 surrounding the UF campus. Table 5 contains daytime, 7am – 7pm, results, while Table 6 has the nighttime, 8pm – 6am, information. The tables also include mean values for quarterly periods and the total year. Again, we note that the monthly average computed for Ar-41 based on operation of the reactor must not exceed the maximum limit of 1.00E-8 Ci/m^3 [9].

Table 5: *Daytime* Monthly, Quarterly, & Yearly Atmospheric Averages (July 2004-2005)

Monthly Quarters, & Year	Temp		Wind Direction	Ground Wind Speed		Pasquill Classes
	F	C	Degrees	mph	m/s	
Jul '04-Sept '04	83.38	28.54	160.77	5.09	2.28	A
Oct '04-Dec '04	69.21	20.67	143.81	6.63	2.96	B
Jan '05-Mar '05	63.73	17.63	182.61	5.31	2.37	C
Apr '05-Jul '05	77.63	25.35	181.25	4.66	2.08	A
Jul '04-Jul '05	73.49	23.05	167.11	5.42	2.42	B

Table 6: *Nighttime* Monthly, Quarterly, & Yearly Atmospheric Averages (July 2004 - 2005)

Monthly Quarters, & Year	Temperature		Wind Direction	Wind Speed		Pasquill Classes
	F	C	Degrees	mph	m/s	
Jul '04-Sept '04	77.89	25.50	158.09	3.10	1.39	F
Oct '04-Dec '04	62.94	17.19	134.13	2.47	1.10	F
Jan '05-Mar '05	57.34	14.08	183.31	3.31	1.48	F
Apr '05-Jul '05	70.90	21.61	166.16	2.66	1.19	F
Jul '04-Jul '05	67.27	19.59	160.42	2.89	1.29	F

The peak Ar-41 concentrations released, for each set of individual data, using possible different Population and Pasquill Class combinations, as well as the distance from the building where these peaks occur, are illustrated in Table 7. Note that highlighted concentrations reflect the average stability classes for each time period.

Table 7: STAC2.1 Urban Ground Peak Ar-41 Concentrations (Ci/m^3) and Distance (m)

Average Stability Classes	Jul04-Sep04		Oct04-Dec04		Jan05-Mar05		April05-Jul05		Jul04-Jul05	
	Ci/m^3	m	Ci/m^3	m	Ci/m^3	m	Ci/m^3	m	Ci/m^3	m
A	2.89E-08	50	2.62E-08	44	2.86E-08	47	2.99E-08	50	2.83E-08	45
B	2.39E-08	79	2.16E-08	75	2.36E-08	78	2.46E-08	82	2.34E-08	80
C	2.32E-08	119	2.09E-08	111	2.28E-08	120	2.39E-08	123	2.27E-08	115
F	1.09E-08	775	1.08E-08	865	1.08E-08	750	1.09E-08	835	1.09E-08	800

The total effective dose equivalent limit determined for Ar-41 is 50 mrem per year at a maximum concentration of 1.00E-8 Ci/m^3, inhaled or ingested continuously over a year [16]. Dose is linearly related to concentration as shown in Eq. (5). Results for the quarterly averages are shown in Table 8. Table 9 shows possible limiting case scenario concentrations and doses for several buildings near the UFTR based on a continuous operation concentration with dedicated winds using the April 2005 – July 2005 data. For this exercise, the wind directions were assumed to vector toward each building.

$$\text{Dose}\,\frac{\text{mrem}}{\text{yr}} = \chi\,\frac{\text{Ci}}{\text{m}^3} * \frac{50\ \text{mrem}}{1.00\,\text{E}-08\ \frac{\text{Ci}}{\text{m}^3}} \qquad (5)$$

Table 8: Total Effective Dose Rate and Maximum STAC2.1 Concentration Values for the Monthly and Yearly Averages for 2004-2005, Assuming Full Power Continuous Operation

Monthly Quarters, & Year	Day Pasquill Classes	Max Day Conc. & Dist. from UFTR		Total Effective Dose Rate
		Ci/m^3	m	mrem/year
Jul '04-Sept '04	A	2.89E-08	50	145
Oct '04-Dec '04	B	2.16E-08	75	108
Jan '05-Mar '05	C	2.28E-08	120	114
Apr '05-Jul '05	A	2.99E-08	50	150
Jul '04-Jul '05	B	2.34E-08	80	117

Table 9: STAC2.1 Total Effective Dose Rate Values for Buildings near the UFTR Assuming dedicated 100% Wind Vectors from the UFTR Stack to the Building

Buildings on Campus	~Distance from UFTR (m)	~Wind Dir. (deg)	Max. Conc. (Ci/m^3)	Dose (mrem/yr)
Reed Lab.	20	180	7.14E-10	4
Weimer Hall	40	265	2.65E-08	133
Weil Hall	63	170	2.89E-08	145
Rhines Hall	91	80	1.96E-08	98
Reitz Student Union	133	0	1.09E-08	55
Mech.& Aerospace Eng. C	137	80	1.03E-08	52
Material Engineering	160	40	7.87E-09	39
East Hall	190	80	5.75E-09	29

Peak concentrations show that when the UFTR is assumed to operate at 100% power for 24 hours per day, then the allowable maximum concentrations and doses of Ar-41 for dedicated wind directions exceed 1.00E-8 Ci/m^3 and 50mrem/yr. This implies a “reactor duty cycle” is needed to bring the monthly average concentration of Ar-41 below the maximum allowable concentrations.

Operation Hours for the UFTR

Using the calculated peak concentrations of Ar-41, the UFTR Effective Full Power Hours (EFPH), are shown in Table 10 for daytime conditions, since daytime is when the reactor is most likely to be run. In considering the peak concentrations, this will decrease all limit exceeding concentrations to below 1.00E-8 Ci/m^3 [9, 16]. EFPH are calculated using Eq. (6) [12, 13].

$$\mathrm{EFPH}\,\frac{\mathrm{hrs}}{\mathrm{mo}} = \frac{1.00\,\mathrm{E}-08\,\frac{\mathrm{Ci}}{\mathrm{m}^3}}{\chi\,\frac{\mathrm{Ci}}{\mathrm{m}^3}} * 720\,\frac{\mathrm{hrs}}{\mathrm{mo}} \tag{6}$$

Ar-41 concentrations (χ) are in Ci/m^3. For units of kW-hours/month or kW-hours/week, one can multiply by 100kW. The 720 hours/month is a standard, assuming 24 hours/day, 7 days/ week, and ~4.286 weeks/month [13]. Note that the EFPH limit based on license requirements is 235.00 hours/month or 55.56 hours/week [13].

Table 10: UFTR Hours of Operation Based on Peak Ar-41 Concentrations (Ci/m^3) for Daytime Atmospheric Conditions

Monthly Quarters, & Year	Day Pasquill Classes	Daytime Max. Conc. & Dist. from UFTR		EFPH			
		Ci/m^3	m	hrs/mo	kW-hrs/mo	hrs/wk	kW-hrs/wk
Jul ‘04-Sept ‘04	A	2.89E-08	50	249.13	24913.49	58.90	5889.72
Oct ‘04-Dec ‘04	B	2.16E-08	75	333.33	33333.33	78.80	7880.22
Jan ‘05-Mar ‘05	C	2.28E-08	120	315.79	31578.95	74.65	7465.47
Apr ‘05-Jul ‘05	A	2.99E-08	50	240.80	24080.27	56.93	5692.73
Jul ‘04-Jul ‘05	B	2.34E-08	80	307.69	30769.23	72.74	7274.05

Therefore, on average, to remain below the annual limit of 1.00E-8 Ci/m^3, the UFTR could be run up ~307 hours/month at full power for the year, with a restriction of running up to ~240 hours/month during the late spring and summer months. However, since the additional licensing restriction is 235.00 hours/month, the UFTR may be run up 235.00 hours/month (or 55.56 hours/week) all year long.

Moreover, since nighttime concentrations are lower than for daytime concentrations, the UFTR can be operated at any time of day, day or night, up to a total of 55.56 hours per week. This is a significant increase from the current EFPH for the UFTR of ~116 hours/month [13].

Dilution Factor for the UFTR

The flow diluted release concentration of Ar-41 (ψ) at the top of the stack, before being affected by the environment, is approximately 1.24E-5Ci/m^3 from Eq. (5). Dilution factors are calculated by dividing concentrations in question by 1.24E-5Ci/m^3. Table 11 shows the dilution factors for the site boundary, the distance where maximum concentration occurs, and the distance where the closest residence housing is located (East Hall at a range of 190m). The concentrations were calculated using the limiting case conditions for April 2005 – July 2005, with a wind direction towards East Hall (80^o).

Table 11: Dilution Ratios based on Concentrations and Relevant Campus Locations

Campus Relevance	Distance from UFTR	Concentration	Dilution Ratio (Value:1)
	m	Ci/m^3	
UFTR Site Boundary	30	1.48E-08	838
Maximum Concentration	50	2.99E-08	415
East Hall (Closest Dorm)	190	5.75E-09	2157

Consider that the dilution ratio for the maximum concentration (415:1) is also the maximum case instantaneous release concentration from the UFTR stack. The dilution ratio, currently used by the UFTR, is 200:1 [13]. Note that 200:1 is extremely conservative compared to the computed value of 415:1 based on results from STAC2.1, which has been shown to be conservative. Table 12 illustrates the difference between the two ratios using the concentration calculated from the UFTR SOP (6.20E-8 Ci/m^3) [12, 13], and the maximum concentration as determined by STAC2.1. It is shown that the 200:1 ratio is approximately 2.07 times more conservative than the 415:1 ratio.

Table 12: Dilution Ratio Comparison

Location	Concentration (Ci/m^3)	Dilution Ratio (Top of stack: Other)	Dilution Ratio (STAC2.1:SOP)
Top of Stack	1.24E-05	N/A	N/A
UFTR SOP (Using 200:1)	6.20E-08	200	2.07
Maximum Concentration	2.99E-08	415	

5. Summary and Conclusions

In summary, UF researchers performed a detailed assessment of the Ar-41 dose generated by operation of the University of Florida Training Reactor (UFTR). In particular, yearly maximum predicted concentrations, dose rates, operational limits, and dilution factors were calculated for the UFTR with impact assessments assuming dedicated wind directions to nearby campus buildings at 100% full power (100kW). A Gaussian plume model based code, STAC2.1, developed and benchmarked by UF researchers, was employed to calculate the maximum concentrations and the distances where they occurred. Average daytime atmospheric conditions for the University of Florida in Gainesville, FL from 2004-2005, UFTR discharge stack parameters, and Ar-41 characteristics were established as input parameters for the code. "By Hand" Pasquill plume calculations, and detailed CALPUFF (a detailed physics model) computations were used to successfully validate STAC2.1 results; the percent differences from the "By Hand" method ranged from 0.70% to 3.61% (Table 2), and the percent differences from CALPUFF models aliased using STAC2.1 were within +/- 19% (Tables 3 – 4).

Based on the available data, the *average* maximum Ar-41 concentration determined using STAC2.1 for the reactor at full power for the year was 2.34E-8 Ci/m^3 down-wind 80m from the UFTR (Table 7). The period from April 2005 – July 2005, the warmest months with the slowest wind conditions, resulted in the highest maximum concentration of 2.99E-8 Ci/m^3 at a down-wind location 50m from the UFTR. This time period and highest maximum concentration was used as the limiting value for the dilution factors, dose rates, and concentrations for the other buildings on campus, as well as the limiting value for full power hours of operation. Concerning the buildings on campus, only buildings within ~150m of the UFTR could experience concentrations and dose rates greater than the limits (Table 9) if the reactor were continuously operated at full power. The student residence hall closest to the UFTR, East Hall, located 190m away, had both the concentration and dose rate below the annual full operation limit: 5.75E-9 Ci/m^3. In order to reduce the maximum concentrations (and corresponding doses) to acceptable limits, the number of allowable full power hours of operation per month were calculated (Table 10). The allowable number of hours, averaged for the year, was ~307 hours/month, with a further restriction during the summer of ~240 full power hours/month. Therefore, based on the current license restriction of 235.00 hours/month, for Ar-41 emissions, the UFTR may be run up to 235.00 hours/month (55.56 hours/week) all year long. This is a significant increase from the current EFPH for the UFTR of ~116 hours/month [13]. In addition, since nighttime concentrations and resultant doses are lower than for daytime, the reactor may be run 55 hours/week continuously without exceeding limit requirements.

Finally, the current dilution factor used in the UFTR SOP is 200:1 to account for atmospheric effects. Based on an analysis of the STAC2.1 results, the limiting dilution ratio is ~415:1 (Table 11). As a result, the 200:1 ratio using in the first half century of licensing was more than twice as conservative as required given the actual ratio of 415:1 (Table 12). Therefore, future dilution ratios should use the correct 415:1 factor.

6. References

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