RAMP Atmospheric Primer: ARCON

Pacific Northwest NATIONAL LABORATORY
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FALL 2020 USERS GROUP VIRTUAL MEETING

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U.S. Nuclear Regulatory Commission Headquarters

JEREMY RISHEL

Atmospheric Scientist

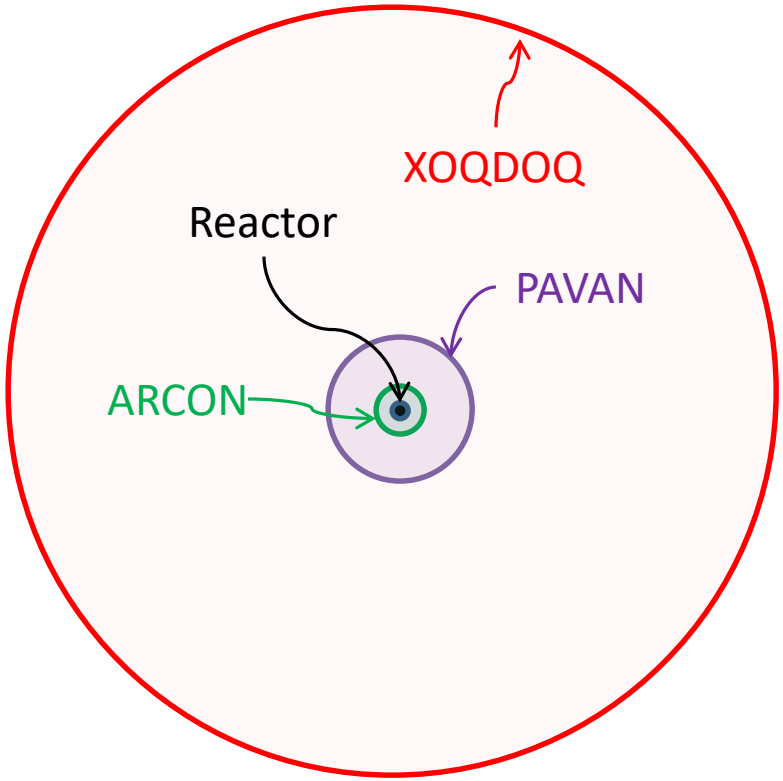
Pacific Northwest National Laboratory

RAMP Atmospheric Codes Overview

- Three atmospheric codes for reactor licensing:
  - ARCON
  - PAVAN
  - XOQDOQ
- Other atmospheric codes in RAMP:
  - RASCAL (for emergency response)
  - HABIT (for assessing control room habitability from chemical releases)

Why Three Atmospheric Codes?

- Three dispersion distances to consider:
  - ARCON: Near-field (~100s meters); design basis accidents (DBA's) at the control room (CR) and technical support center (TSC).
  - PAVAN: Mid-field (~10 km); DBA's at the exclusion area boundary (EAB) and low population zone (LPZ).
  - XOQDOQ: Far-field (out to ~80 km); normal effluent releases for sensitive receptors and population.

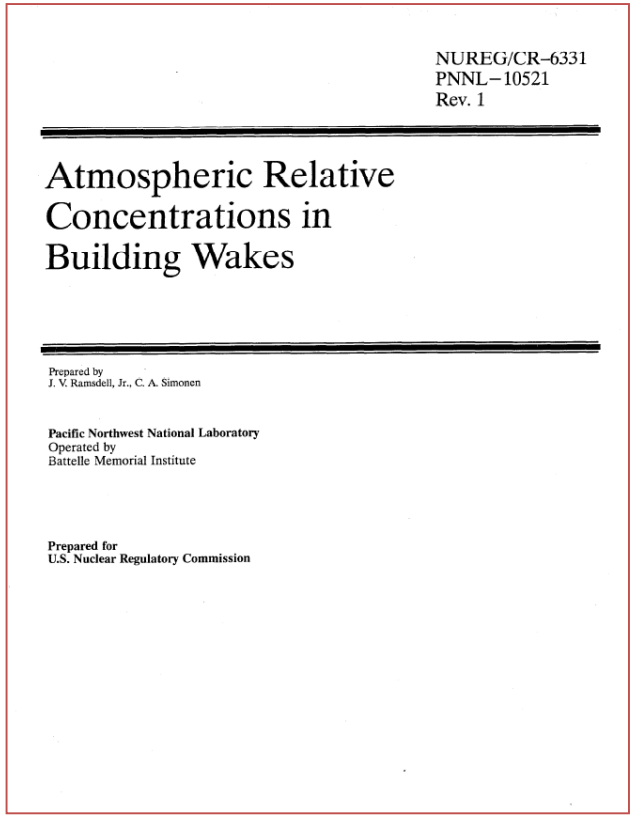


ARCON Overview: Purpose

- Purpose:
  - Atmospheric Relative CONcentrations in Building Wakes
  - Calculate relative air concentrations (χ/Q's) to evaluate control room and technical support center habitability for design basis accidents (10 CFR Part 50)
  - Near-field dispersion
- Users:
  - Nuclear Regulatory Commission (NRC)
  - Department of Energy (DOE)
    - Savannah River Site, South Carolina
    - Hanford Site, Washington

ARCON Overview: Related Guidance

- RG 1.206, C.I.2.3.4: *Short-Term Atmospheric Dispersion Estimates for Accident Releases*
- SRP 2.3.4: *Short-Term Atmospheric Dispersion Estimates for Accident Releases*
- RG 1.194: *Atmospheric Relative Concentrations for Control Room Radiological Habitability Assessments at Nuclear Power Plants (2003)*
- NUREG/CR-6331: *Atmospheric Relative Concentrations in Building Wakes (1997)*
  - ARCON



NUREG/CR–6331
PNNL–10521
Rev. 1

Atmospheric Relative Concentrations in Building Wakes

Prepared by
J. V. Ramsdell, Jr., C. A. Simonen

Pacific Northwest National Laboratory
Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

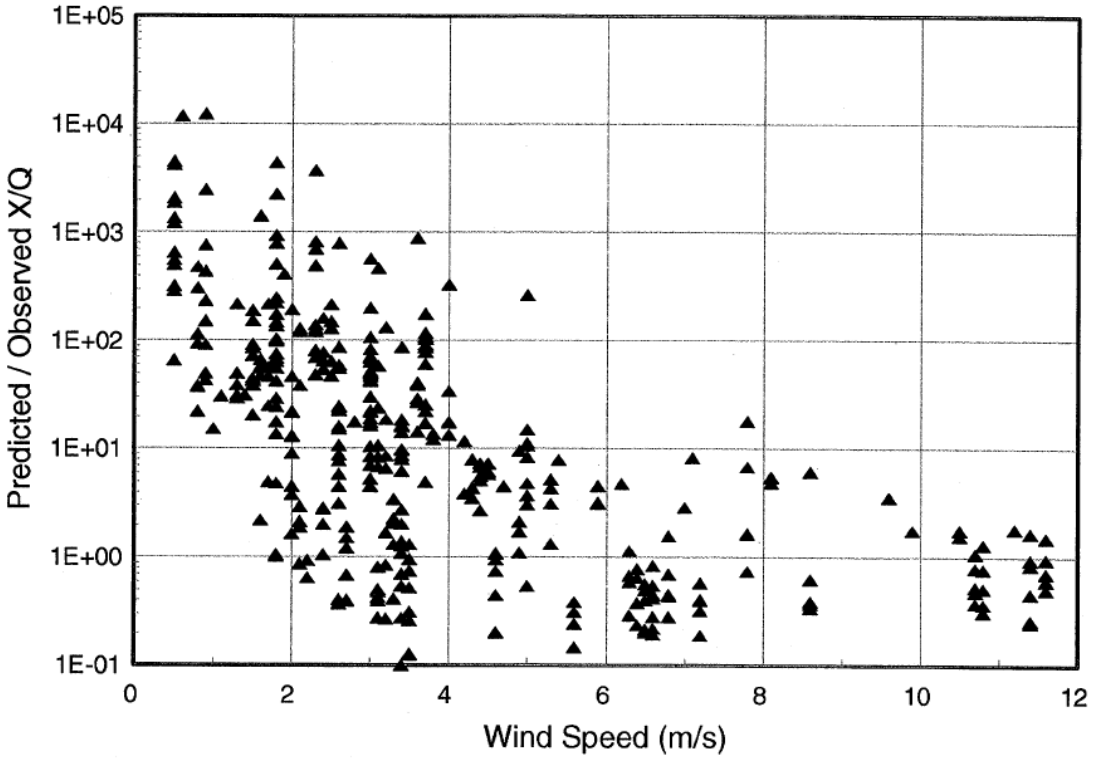
ARCON Overview: Development History

- Developed at Pacific Northwest National Laboratory (PNNL) for the NRC
  - ARCON96
    - Compile Date: June 25, 1997
    - Superseded an earlier version of the code (ARCON95) and included modest changes to how the χ/Q averages were processed.
  - ARCON2
    - Compile Date: September 3, 2020
    - New user interface and incorporates published (Ramsdell and Fosmire, 1998) diffusion adjustment factors

ARCON Overview: Technical Basis

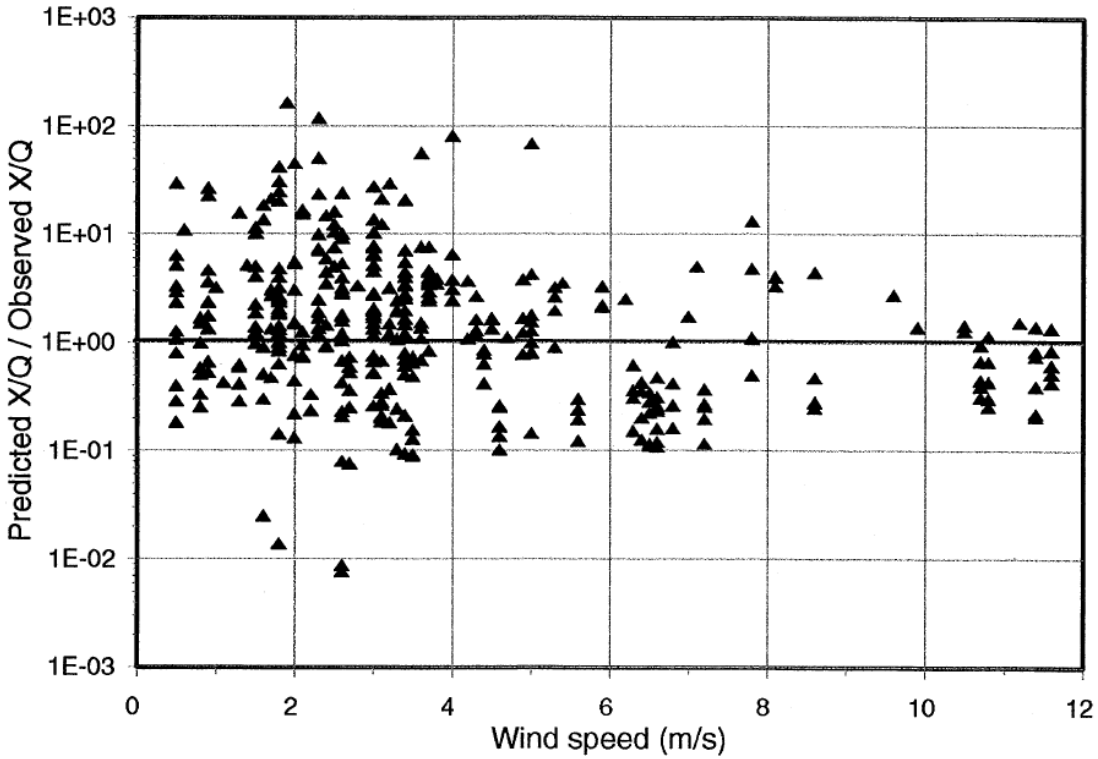
- Straight-line Gaussian plume model
  - Estimates relative concentrations (χ/Q) for defined averaging periods
- Includes enhanced diffusion coefficients:
  - Pasquill-Gifford (most models)
  - Building wake (some models)
  - Low wind speed (few models)
- The building wake and low wind speed diffusion correction factors are based on diffusion data collected in experiments
  - Experiments conducted under a wide-range of meteorological conditions, including low wind speed, when wake effects are small.

ARCON Overview: Standard Diffusion



Ramsdell, Jr., J. V., and C. J. Fosmire. 1998. "Estimating Concentrations in Plumes Released in the Vicinity of Buildings: Model Development." Atmospheric Environment, 32:1663–77.

ARCON Overview: Enhanced Diffusion

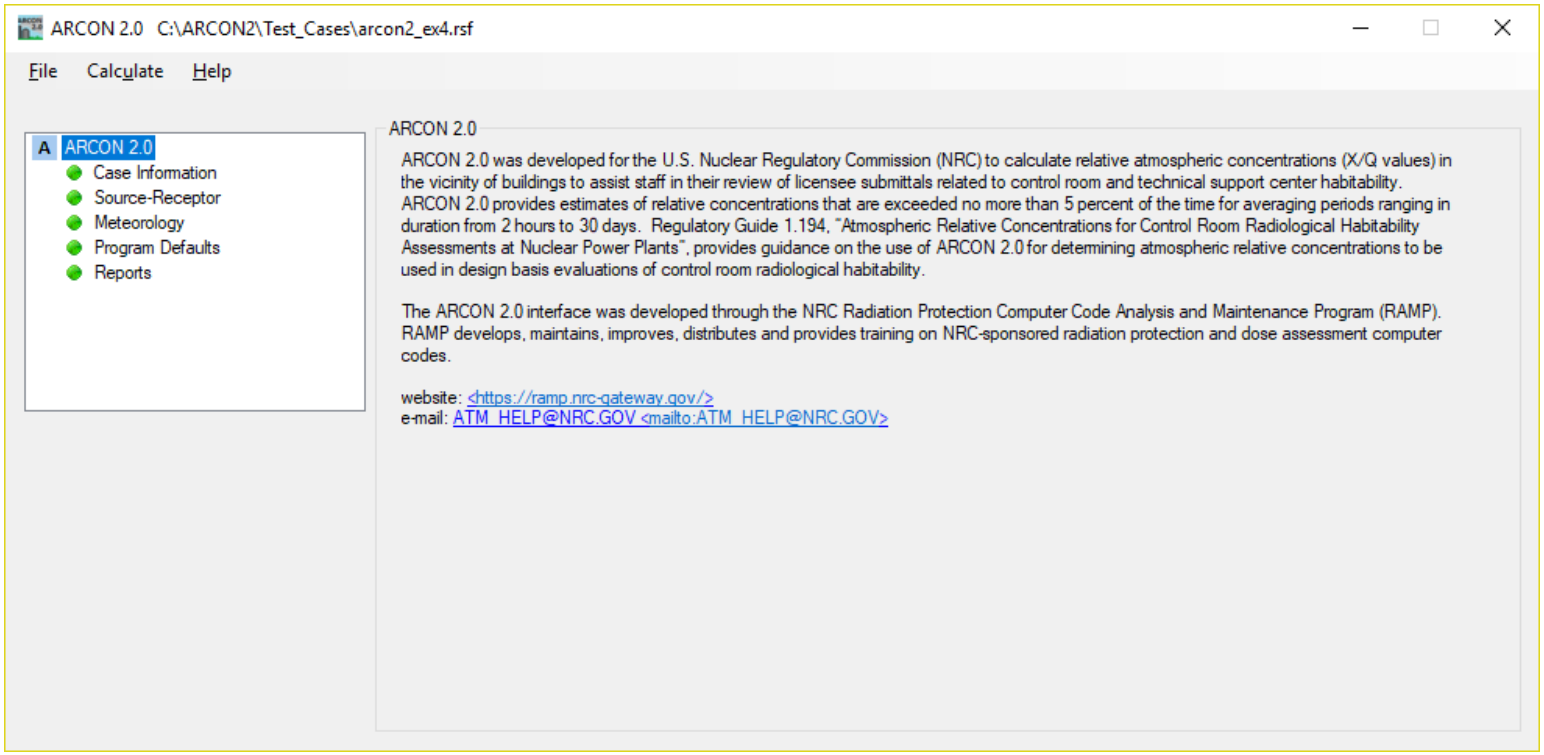


Ramsdell, Jr., J. V., and C. J. Fosmire. 1998. "Estimating Concentrations in Plumes Released in the Vicinity of Buildings: Model Evaluation." Atmospheric Environment, 32:1679–89.

ARCON Overview: Diffusion Summary

- Models using standard diffusion coefficients will tend to over-predict concentrations in the near field at low (i.e., < 4 m/s) wind speeds.
  - This is primarily because the initial Pasquill-Gifford diffusion studies did not consider near-field or low wind speed cases
    - Diffusion curves were “extrapolated” back to the source
- ARCON enhanced diffusion coefficients largely eliminate the bias at lower wind speeds.
  - Even still, experimental data suggests ARCON might slightly over-predict at low wind speeds

ARCON


ARCON 2.0 C:\ARCON2\Test_Cases\arcon2_ex4.rsf
File
Calculate
Help
A ARCON 2.0
Case Information
Source-Receptor
Meteorology
Program Defaults
Reports
ARCON 2.0
ARCON 2.0 was developed for the U.S. Nuclear Regulatory Commission (NRC) to calculate relative atmospheric concentrations (X/Q values) in the vicinity of buildings to assist staff in their review of licensee submittals related to control room and technical support center habitability. ARCON 2.0 provides estimates of relative concentrations that are exceeded no more than 5 percent of the time for averaging periods ranging in duration from 2 hours to 30 days. Regulatory Guide 1.194, "Atmospheric Relative Concentrations for Control Room Radiological Habitability Assessments at Nuclear Power Plants", provides guidance on the use of ARCON 2.0 for determining atmospheric relative concentrations to be used in design basis evaluations of control room radiological habitability.
The ARCON 2.0 interface was developed through the NRC Radiation Protection Computer Code Analysis and Maintenance Program (RAMP). RAMP develops, maintains, improves, distributes and provides training on NRC-sponsored radiation protection and dose assessment computer codes.
website: <https://ramp.nrc-gateway.gov/>
e-mail: ATM_HELP@NRC.GOV <mailto:ATM_HELP@NRC.GOV>

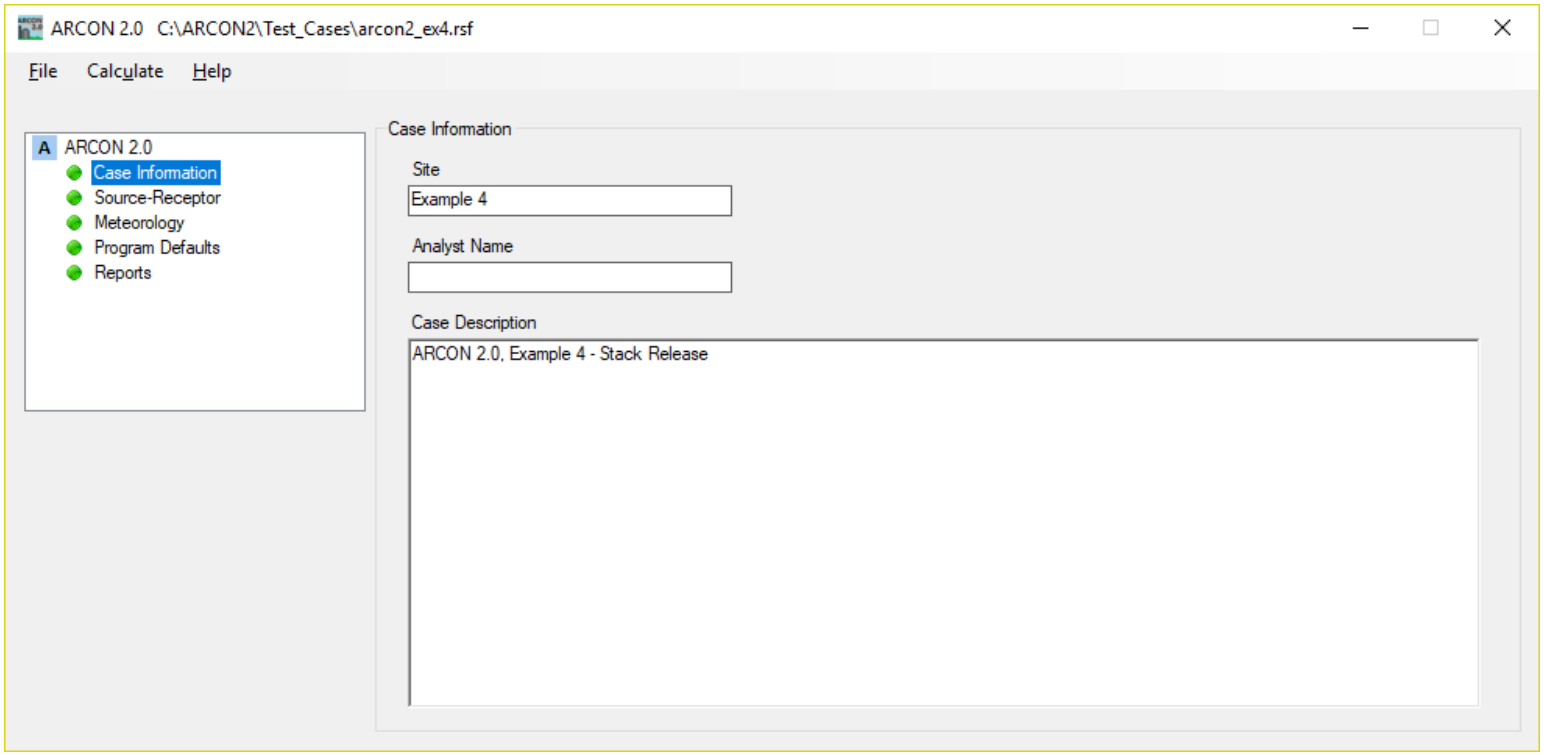
ARCON Inputs & Reports

- Inputs:
  - Case Information
  - Meteorology
  - Source/Receptor
  - Default Data
- Reports
  - Log file (.LOG)
  - Cumulative Frequency Distribution (.CFD)
  - Extended Output (.EXT)

ARCON Inputs: Case Information

- Case information includes:
  - Site
  - Analyst Name
  - Case Description
- Site and analyst information is included at the top of each output file.

ARCON Inputs: Case Information Example



ARCON Inputs: Meteorology

- For meteorology, need to specify:
  - Wind measurement heights (lower and upper)
  - Wind speed unit (m/s, mph, knots)
  - Path to hourly meteorological data files
    - Up to 10 years, in chronological order
    - Either separate files or one large, continuous file

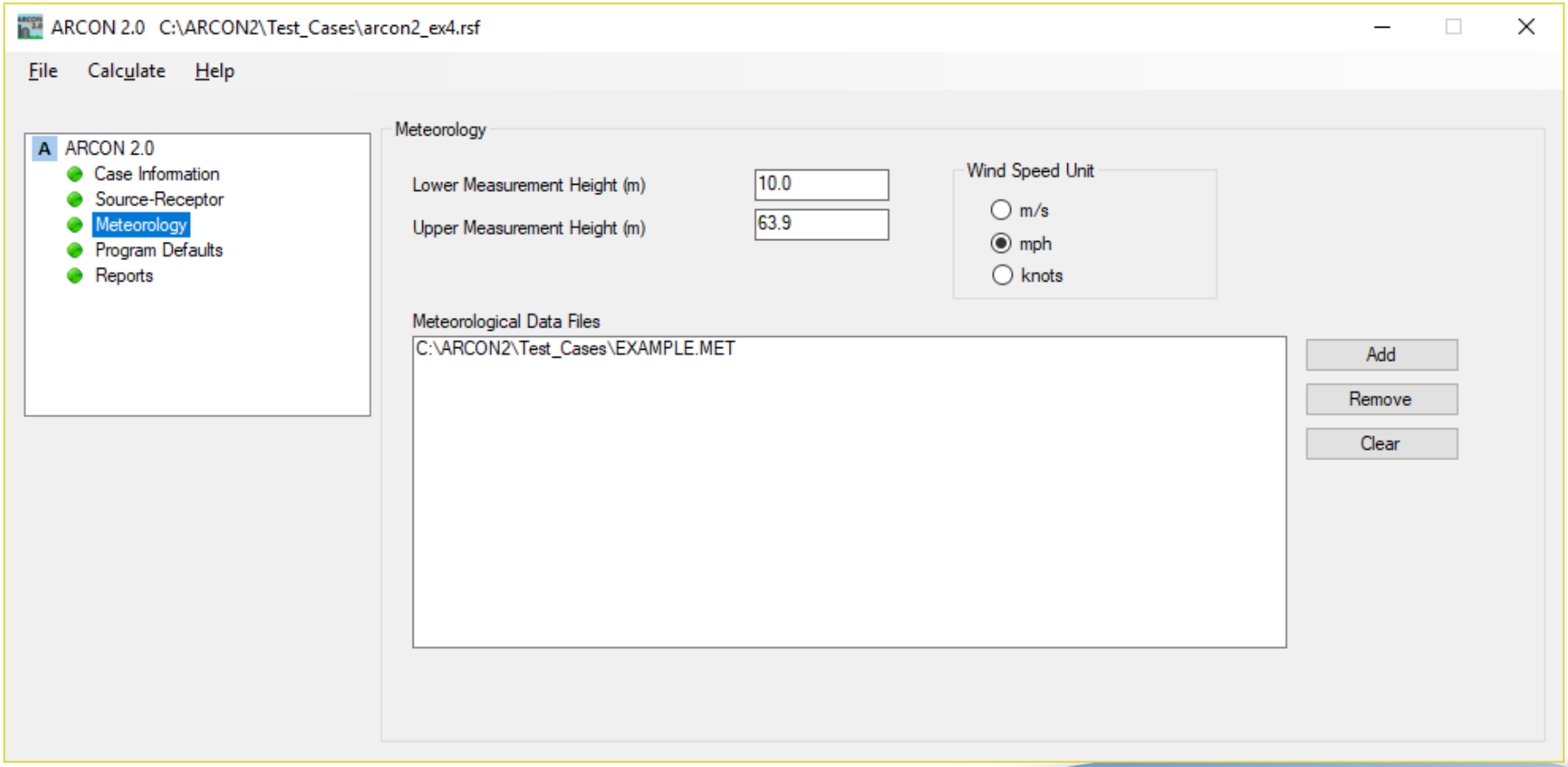
ARCON Inputs: Meteorology (cont'd)

- Hourly file including:
  - Identifier
  - Year
  - Julian day
  - Hour
  - Wind direction and wind speed (lower)
  - Stability class (1-7)
  - Wind direction and wind speed (upper)

```
CPPAL 92  1 1  130  22  4  126  25
CPPAL 92  1 2  118  16  4  111  19
CPPAL 92  1 3  120  14  4  115  18
CPPAL 92  1 4   99  14  4  107  16
CPPAL 92  1 5  122  19  4  119  22
CPPAL 92  1 6  113  17  4  110  18
CPPAL 92  1 7  105  22  4   96  25
CPPAL 92  1 8  117  22  4  113  24
CPPAL 92  1 9  116  25  4  114  29
CPPAL 92  110  131  29  4  128  35
CPPAL 92  111  133  29  4  133  33
CPPAL 92  112  148  21  4  150  25
CPPAL 92  113  151  27  4  153  36
CPPAL 92  114  148  25  4  150  31
CPPAL 92  115  144  25  4  152  32
```

- Wind direction entered in degrees – *direction from*
  - Wind from the north: 360
  - Wind from the east: 90
  - Wind from the south: 180
  - Wind from the west: 270
  - Wind speed is reported to the nearest "tenth", without decimal

ARCON Inputs: Meteorology Example



ARCON Inputs: Source

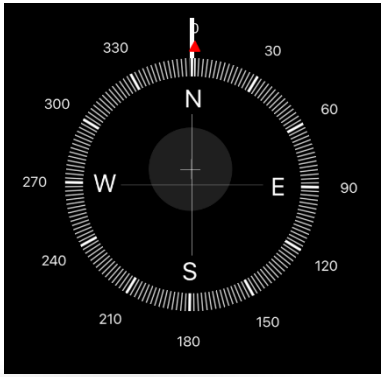
- Type:
  - Ground
  - Vent (“mix-mode”)
  - Stack
- Height:
  - For vent or stack release only
  - 1 to 300 m
  - Plume rise not calculated; calculate separately and add to height

ARCON Inputs: Source (cont'd)

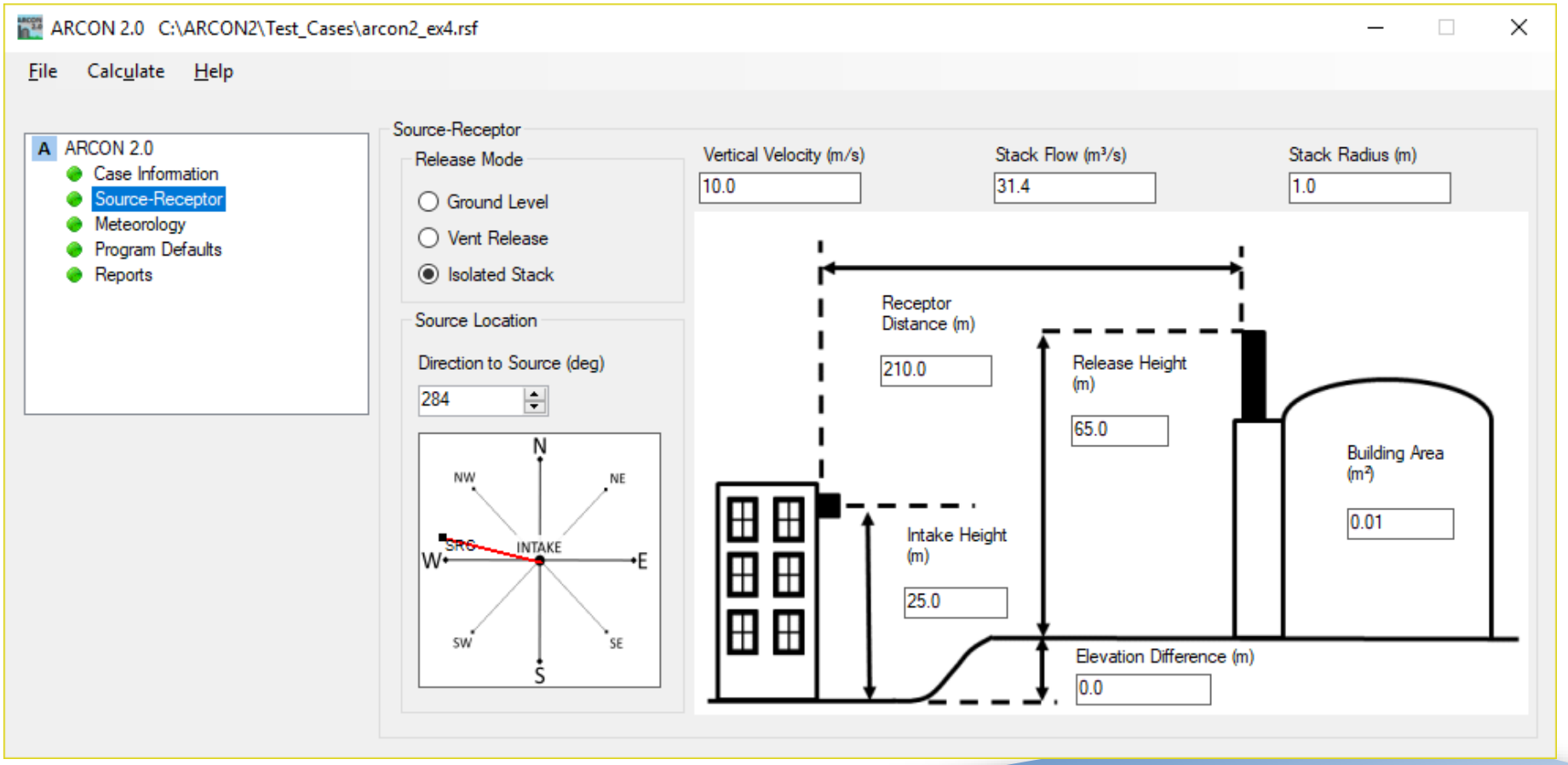
- Vertical velocity: compared to wind speed (vertical velocity/wind speed)
  - Vent:
    - If > 5, exhaust is elevated
    - If < 1, exhaust trapped in wake
    - In between, partial plume in wake (mix-mode)
  - Stack: stack-tip downwash
    - If < 1.5, downwash
- Building area:
  - Ground or vent release only
  - Projected building area upwind of the receptor
  - 0.1 to 10,000 m^2

ARCON Inputs: Receptor

- Distance to receptor
  - ≤ 10,000 m
- Height (e.g., control room intake)
  - ≤ 100 m
- Elevation difference
  - Difference between source elevation and receptor elevation
  - > 0 if source elevation > receptor elevation
  - < 0 if source elevation < receptor elevation
  - -1,000 m to 1,000 m
- Direction to source
  - Use meteorological (compass) coordinate system
  - Reference frame is from the receptor
  - Look “upwind” toward source



ARCON Inputs: Source-Receptor Example



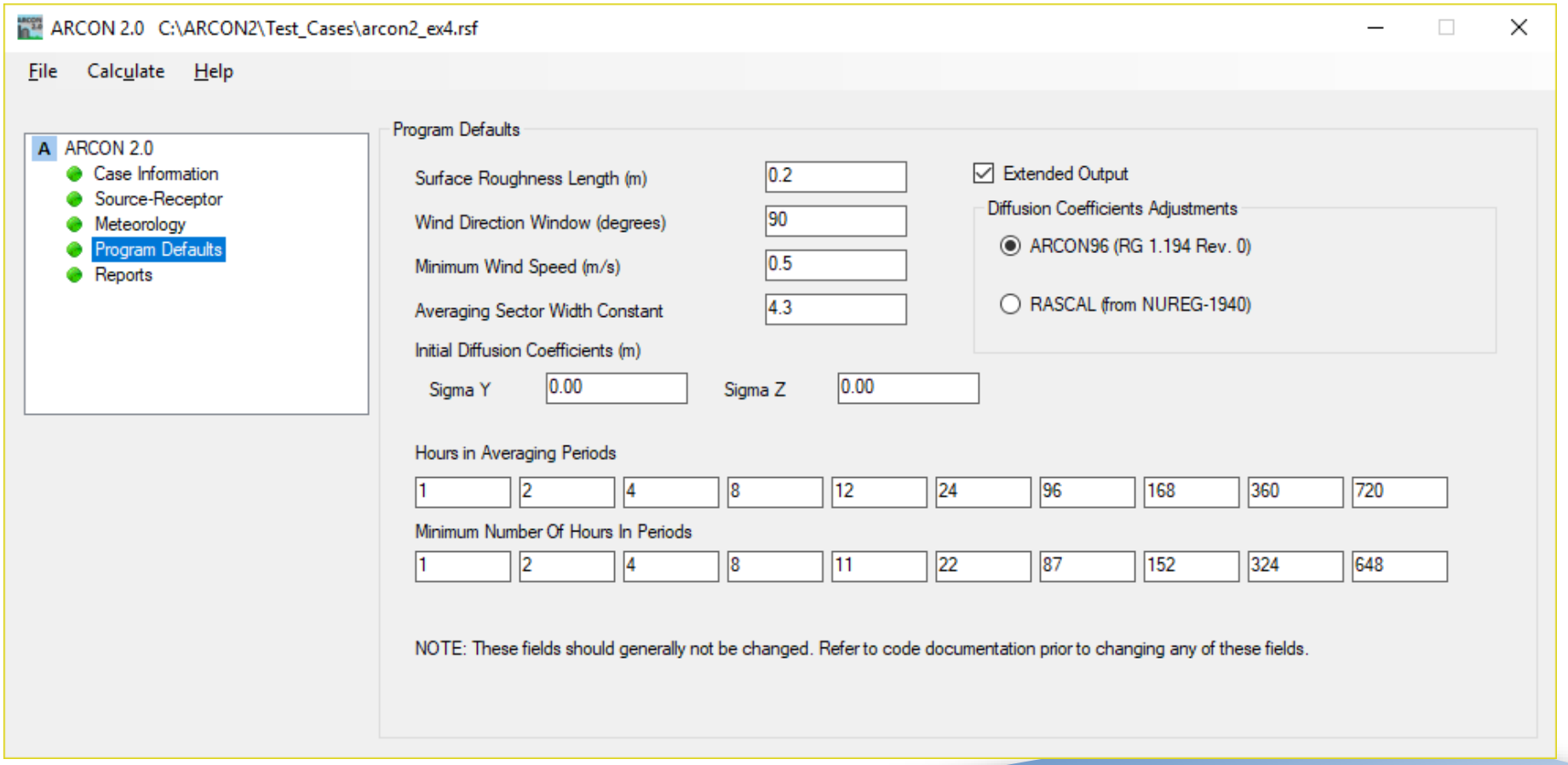
ARCON Inputs: Program Defaults

- Default inputs that can be changed in ARCON:
  - Surface roughness (meters)
    - Used in scaling the wind speed to release height
    - Default value: 0.2 meters
  - Wind direction window (degrees)
    - Plumes within the direction window assumed to affect the receptor
    - Default value: 90º (± 45º from plume centerline)
  - Initial diffusion coefficients (m)
    - For diffuse area sources
    - Adjustments made to the point source diffusion coefficients
    - Recommend value: depends on source
    - Default value: 0 m
  - Minimum wind speed (m/s)
    - Minimum wind speed used to define “calm” winds
    - Wind direction not used; plume is conservatively placed in all directions
    - Default value: 0.5 m/s

ARCON Inputs: Program Defaults (Cont'd)

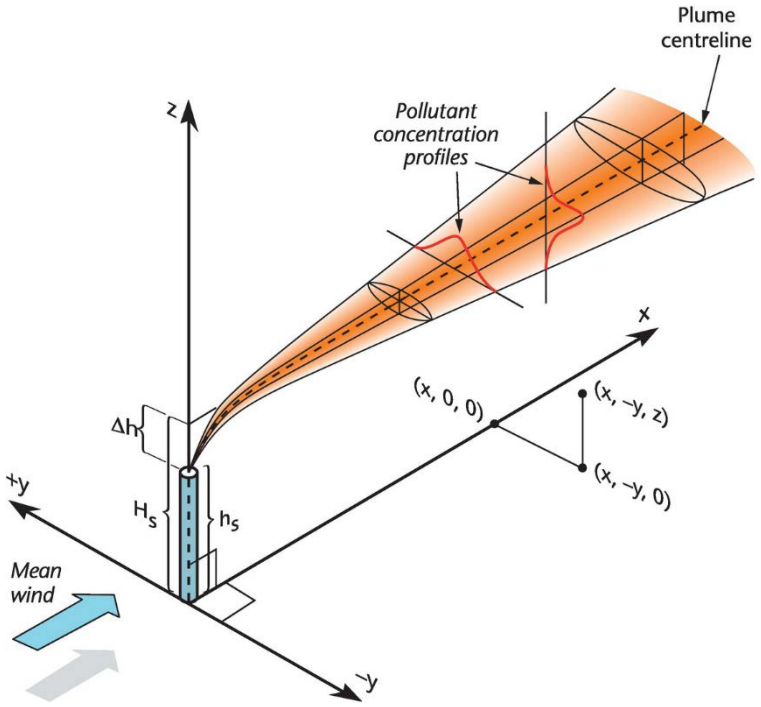
- Default inputs that can be changed in ARCON:
  - Averaging Sector Width Constant
    - Used in the sector-average model
    - 95% of the plume is within ± 2 sigma-y
    - Recommended value: between 4 and 6; default of 4.3
  - Hours in Averaging Periods
    - Computed averaging times
    - Used for different NRC design basis accident intervals
    - Recommend values: 1, 2, 4, 8, 12, 24, 96, 168, 360, 720 hours
  - Minimum Number of Hours in Periods
    - Recommend values: 1, 2, 4, 8, 11, 22, 87, 152, 324, 648 hours

ARCON Inputs: Program Defaults Example



ARCON Outputs

- ARCON Averages:
  - Short-term average (≤ 8 hours):
    - Centerline χ/Q only
  - Longer-term average (> 8 hours):
    - Centerline χ/Q for first 8 hours and sector-average χ/Q for rest of period
    - Sector average accounts for the fact that the plume does not exactly travel down the centerline over longer averaging periods



ARCON Outputs (cont'd)

- Three report files:
  - Log (.LOG) file
    - Primary output file summarizing the model results
    - 95th percentile values
  - Cumulative Frequency Distribution (.CFD) file
    - Contains the CFD for each averaging period
  - Extended (.EXT) file
    - Values for scenario-dependent parameters calculated during program initialization
    - Listing of the meteorological data read by the program
    - Listing of the hourly centerline and sector-average χ/Qs
    - Frequency distributions for each of the averaging periods.

ARCON Reports: LOG File

DISTRIBUTION SUMMARY DATA BY AVERAGING INTERVAL

AVER. PER.	1	2	4	8	12	24	96	168	360	720
UPPER LIM.	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02	1.00E-02
LOW LIM.	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06	1.00E-06
ABOVE RANGE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
IN RANGE	2585.	2887.	3360.	4055.	4603.	5824.	8381.	8633.	8461.	8137.
BELOW RANGE	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
ZERO	6197.	5892.	5413.	4706.	4171.	2939.	317.	0.	0.	0.
TOTAL X/Qs	8782.	8779.	8773.	8761.	8774.	8763.	8698.	8633.	8461.	8137.
% NON ZERO	29.44	32.89	38.30	46.28	52.46	66.46	96.36	100.00	100.00	100.00

95th PERCENTILE X/Q VALUES

9.73E-04	9.05E-04	8.59E-04	7.87E-04	6.42E-04	4.79E-04	3.00E-04	2.63E-04	2.31E-04	2.25E-04

95% X/Q for standard averaging intervals

0 to 2 hours	9.73E-04
2 to 8 hours	7.26E-04
8 to 24 hours	3.25E-04
1 to 4 days	2.40E-04
4 to 30 days	2.14E-04

HOURLY VALUE RANGE

	MAX X/Q	MIN X/Q
CENTERLINE	1.31E-03	1.39E-04
SECTOR-AVERAGE	8.23E-04	8.69E-05

ARCON Reports: CFD File

Program Run: 8/ 7/2018 at 08:06:49
User:
Project:

X/Q CUMULATIVE FREQUENCY DISTRIBUTIONS

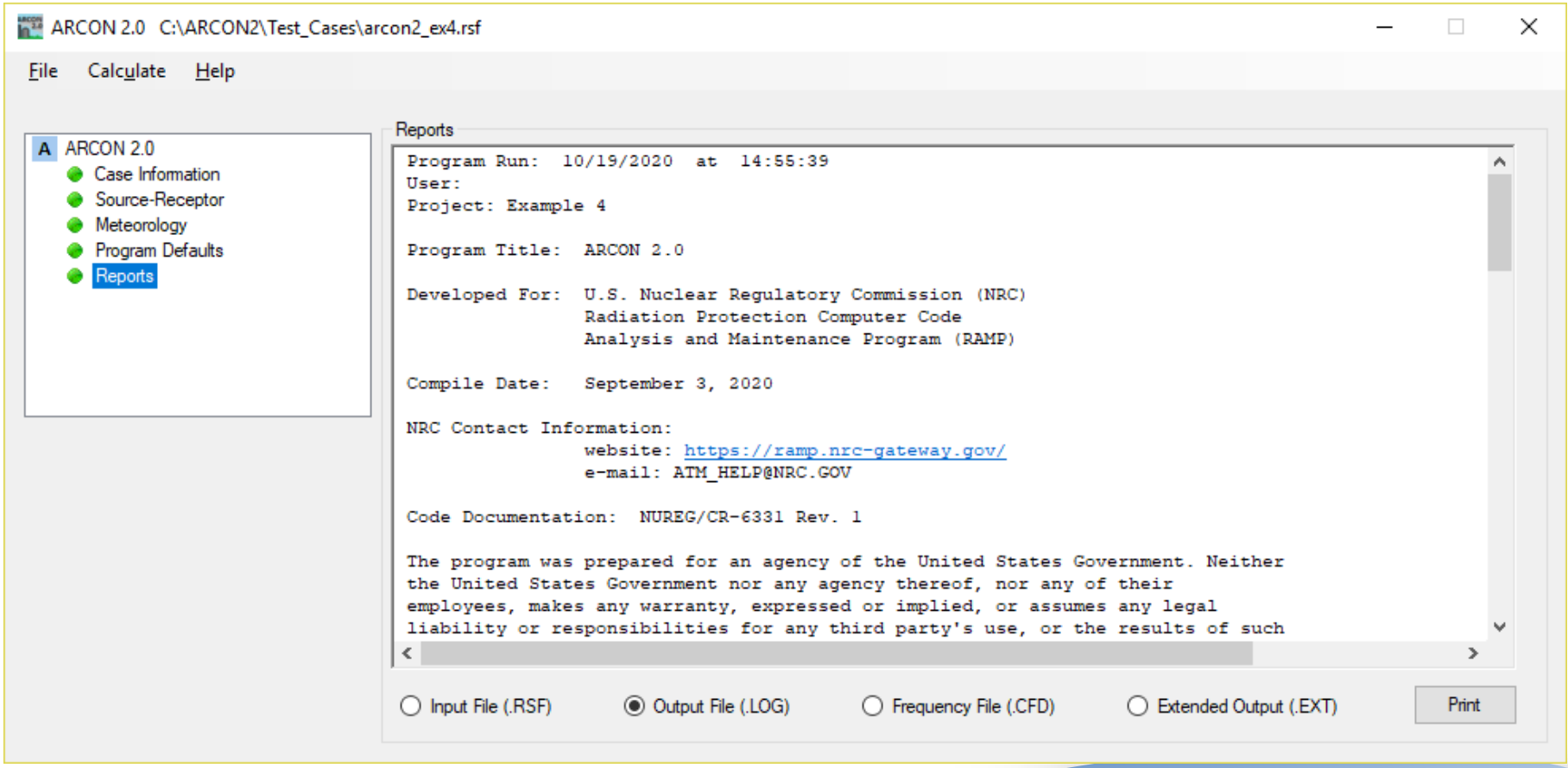
XOQ	1	2	4	8	XOQ	12	24	96	168	360	720
Abv. Lim.	0.	0.	0.	0.	Abv. Lim.	0.	0.	0.	0.	0.	0.
9.120E-03	0.	0.	0.	0.	9.120E-03	0.	0.	0.	0.	0.	0.
8.318E-03	0.	0.	0.	0.	8.318E-03	0.	0.	0.	0.	0.	0.
7.586E-03	0.	0.	0.	0.	7.586E-03	0.	0.	0.	0.	0.	0.
6.918E-03	0.	0.	0.	0.	6.918E-03	0.	0.	0.	0.	0.	0.
6.310E-03	0.	0.	0.	0.	6.310E-03	0.	0.	0.	0.	0.	0.
5.754E-03	0.	0.	0.	0.	5.754E-03	0.	0.	0.	0.	0.	0.
5.248E-03	0.	0.	0.	0.	5.248E-03	0.	0.	0.	0.	0.	0.
4.786E-03	0.	0.	0.	0.	4.786E-03	0.	0.	0.	0.	0.	0.
4.365E-03	0.	0.	0.	0.	4.365E-03	0.	0.	0.	0.	0.	0.
3.981E-03	0.	0.	0.	0.	3.981E-03	0.	0.	0.	0.	0.	0.
3.631E-03	0.	0.	0.	0.	3.631E-03	0.	0.	0.	0.	0.	0.
3.311E-03	0.	0.	0.	0.	3.311E-03	0.	0.	0.	0.	0.	0.
3.020E-03	0.	0.	0.	0.	3.020E-03	0.	0.	0.	0.	0.	0.
2.754E-03	0.	0.	0.	0.	2.754E-03	0.	0.	0.	0.	0.	0.
2.512E-03	0.	0.	0.	0.	2.512E-03	0.	0.	0.	0.	0.	0.
2.291E-03	0.	0.	0.	0.	2.291E-03	0.	0.	0.	0.	0.	0.
2.089E-03	0.	0.	0.	0.	2.089E-03	0.	0.	0.	0.	0.	0.
1.905E-03	0.	0.	0.	0.	1.905E-03	0.	0.	0.	0.	0.	0.
1.738E-03	0.	0.	0.	0.	1.738E-03	0.	0.	0.	0.	0.	0.
1.585E-03	0.	0.	0.	0.	1.585E-03	0.	0.	0.	0.	0.	0.
1.445E-03	0.	0.	0.	0.	1.445E-03	0.	0.	0.	0.	0.	0.
1.318E-03	0.	0.	0.	0.	1.318E-03	0.	0.	0.	0.	0.	0.
1.202E-03	74.	47.	20.	4.	1.202E-03	0.	0.	0.	0.	0.	0.
1.096E-03	211.	148.	76.	12.	1.096E-03	0.	0.	0.	0.	0.	0.
1.000E-03	382.	272.	171.	57.	1.000E-03	0.	0.	0.	0.	0.	0.
9.120E-04	565.	418.	298.	154.	9.120E-04	5.	0.	0.	0.	0.	0.
8.318E-04	801.	643.	510.	308.	8.318E-04	41.	0.	0.	0.	0.	0.
7.586E-04	1084.	905.	769.	522.	7.586E-04	128.	0.	0.	0.	0.	0.
6.918E-04	1318.	1131.	1012.	755.	6.918E-04	275.	2.	0.	0.	0.	0.
6.310E-04	1553.	1343.	1246.	1023.	6.310E-04	476.	24.	0.	0.	0.	0.
5.754E-04	1813.	1670.	1541.	1404.	5.754E-04	749.	88.	0.	0.	0.	0.
5.248E-04	1998.	1936.	1821.	1706.	5.248E-04	1051.	228.	0.	0.	0.	0.
4.786E-04	2170.	2142.	2028.	1923.	4.786E-04	1439.	439.	1.	0.	0.	0.

ARCON Reports: EXT File

Subroutine XOQCALC5

1	4	2.20	2.34	126	0.00E+00	0.00E+00
2	4	1.60	1.78	111	0.00E+00	0.00E+00
3	4	1.40	1.68	115	0.00E+00	0.00E+00
4	4	1.40	1.50	107	0.00E+00	0.00E+00
5	4	1.90	2.06	119	0.00E+00	0.00E+00
6	4	1.70	1.68	110	0.00E+00	0.00E+00
7	4	2.20	2.34	96	0.00E+00	0.00E+00
8	4	2.20	2.25	113	0.00E+00	0.00E+00
9	4	2.49	2.71	114	0.00E+00	0.00E+00
10	4	2.89	3.27	128	0.00E+00	0.00E+00
11	4	2.89	3.09	133	0.00E+00	0.00E+00
12	4	2.10	2.34	150	1.04E-03	6.55E-04
13	4	2.69	3.37	153	8.85E-04	5.55E-04
14	4	2.49	2.90	150	9.57E-04	6.00E-04
15	4	2.49	2.99	152	9.43E-04	5.91E-04
16	4	2.69	2.90	124	0.00E+00	0.00E+00
17	4	3.09	3.27	115	0.00E+00	0.00E+00
18	4	2.30	2.62	137	1.00E-03	6.27E-04
19	4	2.79	3.27	123	0.00E+00	0.00E+00
20	4	2.99	3.65	118	0.00E+00	0.00E+00
21	4	3.49	4.21	121	0.00E+00	0.00E+00
22	4	3.39	4.12	124	0.00E+00	0.00E+00
23	4	3.39	4.12	121	0.00E+00	0.00E+00
24	4	3.19	3.93	122	0.00E+00	0.00E+00
25	4	3.29	4.02	121	0.00E+00	0.00E+00
26	4	3.29	4.40	126	0.00E+00	0.00E+00
27	4	3.49	4.58	130	0.00E+00	0.00E+00
28	4	3.09	4.21	137	7.67E-04	4.80E-04
29	4	3.29	4.49	140	7.30E-04	4.58E-04

ARCON Reports Example



Questions?

- *Jeremy Rishel*
  - *Mr. Rishel supports the RAMP Atmospheric Codes, including ARCON, PAVAN, and XOQDOQ. In addition, Mr. Rishel supports the development of the NRC's RASCAL emergency response code.*
  - *Email: jeremy.rishel@pnnl.gov*
  - *Phone: 509-375-6974*