XOQDOQ Calculation – Method, Tools and Pitfalls

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Abstract

XOQDOQ calculation models the concentration and deposition of routine radioactive effluent releases dispersed through the atmosphere. Changes in land use and population around nuclear plants, as well as regulatory guidelines may prompt recalculation of XOQDOQ.

This presentation defines the terms XOQ (X over Q, X/Q, Chi over Q, χ/Q, χ/Q) - the average effluent concentration normalized by source strength, and DOQ (D over Q, D/Q) - the average relative deposition per unit area. It discusses the terms' meaning and the application of the computed values.

This presentation then reviews the processes performed in the XOQDOQ calculation: the modeling of plume behavior; decay and deposition; building, vent and terrain allowances; and distribution based on wind speed, direction and stability class. Then receptors are discussed along with how the program determines XOQ and DOQ values for standard directions and distances as well as specific receptor locations.

Several versions of the XOQDOQ program were available for mainframes and minicomputers, including customized versions at different sites. The standard version of the program has been converted to run on current PC's and is available from RSICC. This presentation shows how to use the available XOQDOQ computational engine directly, or with front end programs that provide a user interface to the engine.

This presentation concludes with a description of some items to note, related to the internal implementation of the XOQDOQ engine and its primitive input options, when preparing input or analyzing output. These include inconsistent use of engineering units, the required format of wind data (which may be counterintuitive to users of other meteorological programs) and the method of distinguishing elevated, mixed and ground releases.

Introduction

XOQDOQ calculation models the concentration and deposition of routine radioactive effluent releases dispersed through the atmosphere. Emphasis should be placed on the words *routine* and *atmosphere*. This program estimates the distribution of routine or periodic releases which are carried by a plume away from the release site, based on yearly or seasonal wind data. Larger single events, spills or liquid releases require other processing.

XOQ (X over Q, X/Q, Chi over Q, χ/Q, χ/Q) – is defined as the average effluent concentration normalized by source strength. It is a function of the release conditions, wind data, and the distance and direction from the release point. The units are *seconds per cubic meter*. These units may seem unusual, but XOQ multiplied by the intensity of the release produces an exposure level at the receptor location.

DOQ (D over Q, D/Q) is defined as the average relative deposition per unit area. It is also a function of the release conditions, wind data, and the distance and direction from the release point, and is computed for components of the release that deposit out of the plume (depletion in XOQDOQ terminology). The units are *per cubic meter*. Again, unusual units but multiplication by the intensity of the release produces an intensity at the receptor location.

XOQ and DOQ were probably calculated early in each plant's history, but subsequent changes in plant vents, wind conditions, or most likely land use and population around nuclear plants or regulatory guidelines may prompt recalculation of XOQDOQ.

The following sections summarize the inputs required to run the XOQDOQ program, the internal process performed by the program, and the outputs available from the program. Then follows some practical aspects of acquiring the current XOQDOQ program and interfaces that may be used with it. Finally, some unusual behaviors and things to watch out for when running the XOQDOQ program are listed.

Inputs – What You Need To Know To Run the Program

To generate an XOQDOQ report, the user needs to describe the release conditions, the terrain around the plant, the receptor locations and wind information. Whether or not an interface program is available to simplify data entry, the *XOQDOQ: Computer Program for the Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations* manual serves as the definitive reference for all of the input parameters.

Releases

A release describes the characteristics of the vent, building characteristics, and the decay properties of the release.

Vent height	- initial estimate of plume height
Vent velocity	- vent velocity increases effective plume height
Vent diameter	- certain vent diameter and velocity combinations lower effective plume height due to downwash
Emission rate	- (heat) can increase effective plume height due to buoyancy
Release type	- Elevated, Ground or Mixed
Wind Height	- Set to vent height
Building height	- interference for ground and mixed releases
Building cross section	- interference for ground and mixed releases
Purge indicator	- indicates if periodic purges are done, and if so type of decay
Purge number	- number of purges per year
Purge duration	- length of purge
Decays	- up to 3 release products, half-life and depletion indicator - defaults are: 1) no decay / no depletion 2) Xe_{133m} – half life 2.26 days no depletion 3) I_{131} – half life 8 days with depletion

Receptors

What is a receptor? You may be one. A receptor is a location of interest around the plant where a release may intersect with people or agricultural area. It is defined by a direction and a distance from the vent.

For human activity, these may be business areas or population centers (cities, villages or suburbs). A category for residences may also be monitored. Residences are usually defined as the homes nearest to the release point in each of the directional sectors around the release.

Because of different uptake paths for different isotopes, several agricultural categories may be established (e.g. milk animals, meat animals, gardens or crops).

For regulatory reasons, the plant boundary may also be defined as a set of receptors.

Terrain & Correction Factors

For plants located on flat or gently rolling terrain, the default of open terrain and the standard correction curve should be selected. Plants located in a desert require an option setting that uses different curves in some of the internal calculations.

For plant sites with more interesting topography such as valleys, the user may specify the surrounding terrain by entering elevations for selected distances in each of the directional sectors around the plant. These elevations may be referenced to plant grade, or the plant grade may be entered and the terrain elevations entered relative to sea level.

The standard correction curve is a multiplier that is a function of distance from the release. It is applied to the calculation to account for recirculation and stagnation. A simplified view of this is that exposure is greater near the release than otherwise calculated due to shifting winds carrying release material back and forth as the wind changes, and this effect diminishes as you move away from the vent.

Users may specify site specific recirculation factors in a similar manner to entering terrain data, but determining these factors requires advanced modeling techniques or site diffusion experiments.

Options

Several options are defined in the XOQDOQ documentation, but many related to alternate output were not implemented in the current PC version of the program. Also the option to use a cubic spline for interpolation and the option to compute a sector spread are not implemented.

The options related to specifying Joint Frequency Distribution (JFD) data and recirculation parameters are implemented and have been mentioned above in their respective sections.

Wind Data

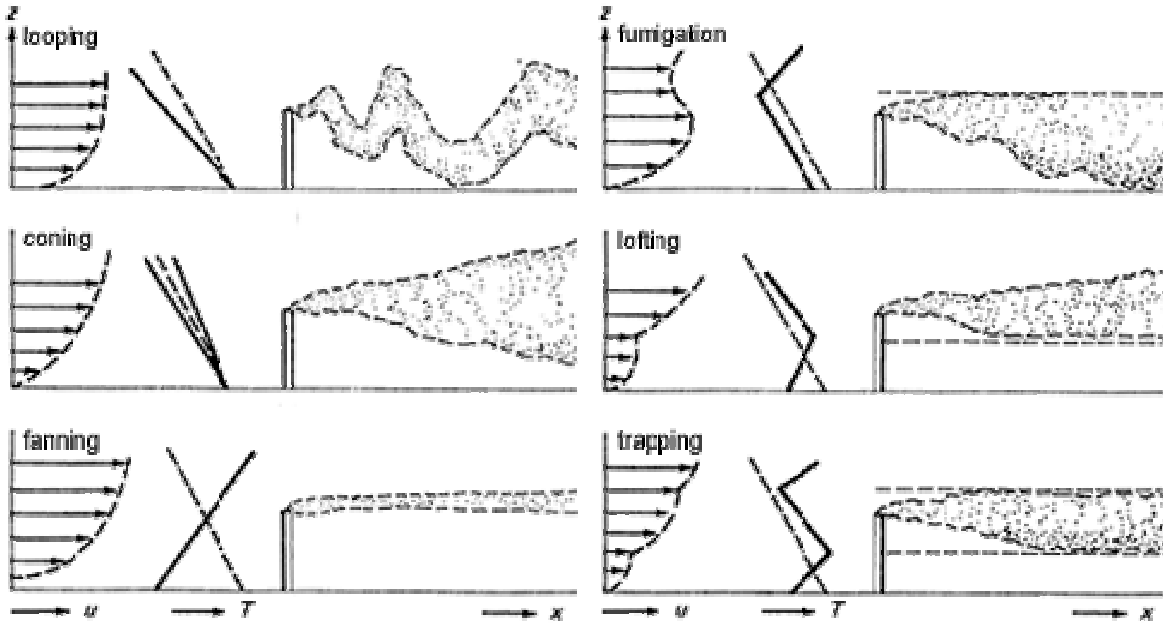
Calms	- select option to specify calms and let them be distributed to different directions, or include calms in the lowest wind speed category
Counts	- specify wind data as counts or percentage
Sectors	- defaults to 22.5^{o} sectors, option for 20^{o} sectors with 30^{o} for N, E, S & W
Velocity	- number of velocity categories
Stability	- number of stability classes
Height	- sensor height of JFD data
Calms	- enter calms if letting program distribute calms
JFD	- Joint Frequency Distribution (wind data)
Correction	- (unit correction) specifies whether wind speed is miles/hour or meters/sec
MaxSpeed	- the maximum speed per wind speed category

Process

The XOQDOQ program creates a Gaussian model of a simple plume using standard deviation (sigma) values derived from the stability class of the wind data. Corrections are made for decay and deposition, building effects, vent conditions and terrain effects.

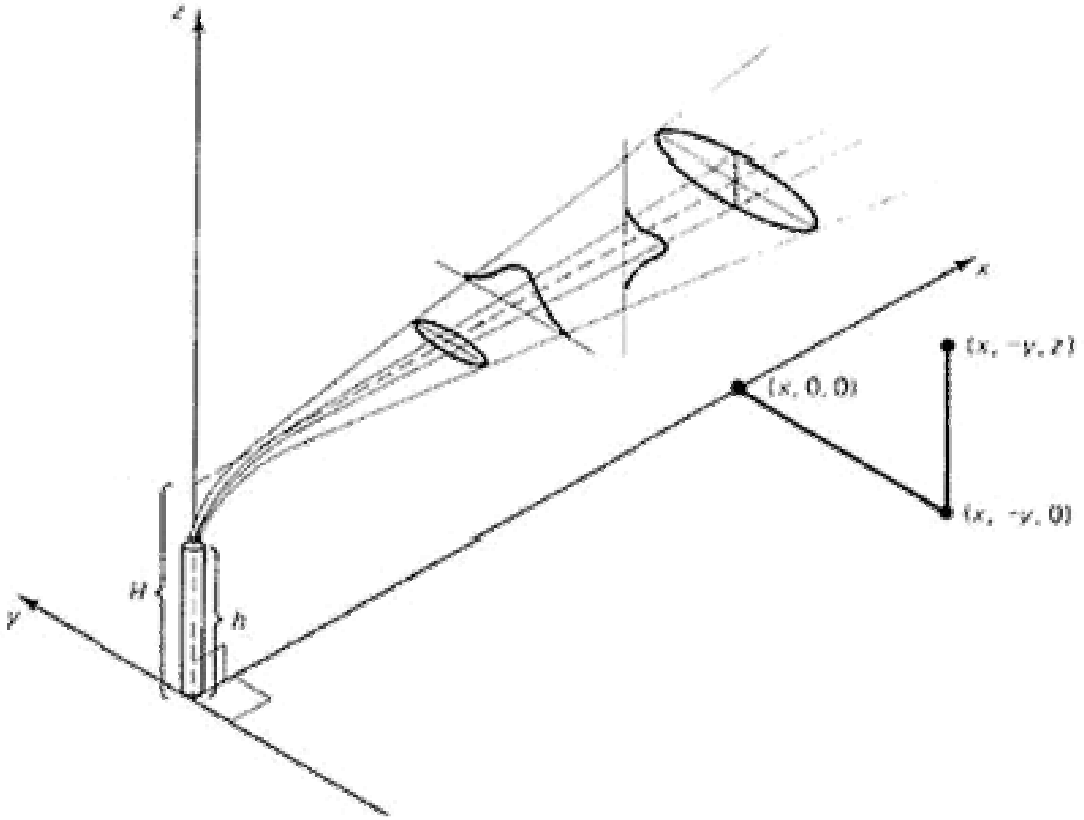
Plume Behavior

In real world situations, many types of plume behaviors are observed. The particular behavior is determined by the wind and temperature profiles of the atmosphere. Some examples are shown in the following figure.



Typical Plume Behaviors

The XOQDOQ program has no facility for using these atmospheric profiles even if they were available. It models coning behavior of the plume and uses the stability class in determining both the horizontal and vertical dispersion of the plume. It does make some compensation for terrain.



Plume Distribution

Elevated Releases

For a stack release, the initial effective plume height is the height of the stack. This may be increased or decreased depending on the release conditions. A high stack velocity will increase the effective height of the plume due to momentum. A high temperature release (unusual in nuclear applications) will also raise the effective plume height due to buoyancy of the release. A low velocity release from a large diameter stack, on the other hand, will produce a lower effective height from downwash due to aerodynamic effects around the stack.

Building Effects & Terrain

For ground release, or mixed releases (vents at approximately the height of nearby buildings), additional dispersion is computed to account for building wakes. Changes in terrain height are translated into changes in the effective plume height.

Decay and Depletion

Material that is propagated through the plume may lose intensity by radioactive decay, by depositing out of the plume, or both. Decay reduces the XOQ values at greater distances (and hence longer times) from the vent. Deposits out of the plume create the DOQ values. Material that is deposited out of the plume depletes the plume, hence the use of both terms.

Recirculation & Stagnation

The computation method described below would tend to produce too low an estimate of XOQ and DOQ for areas near the release point. A correction factor has been added to the method to account for recirculation, where shifting winds near the release point move material back and forth over some areas and stagnant areas where released material may linger in the atmosphere.

Method

For each of 22 specific distances and 16 directions from the release (352 points), an XOQ value is computed as follows:

1) A Gaussian distribution is computed as: $\dfrac{e^{-\frac{1}{2}\left(\frac{h_e}{\sigma_z}\right)^2}}{(\text{wind velocity})\ \sigma_y\ \sigma_z}$ for each wind velocity and stability class category where:

h_e = the effective stack height at this distance

σ_y = sigma in the horizontal (cross wind) direction

σ_z = sigma in the vertical direction

The σ_y and σ_z values are computed from the distance and stability class.

2) The Gaussian distribution is multiplied by the fraction of the sample period represented by this wind velocity, direction, and stability class category.

3) Decay and depletion factors are multiplied by this value.

4) All of the values are summed together.

5) The XOQ value is computed for the point by multiplying the above result by a constant, the recirculation correction factor, and dividing by the distance.

DOQ is computed in a similar manner.

When the XOQ and DOQ values has been determined for each of the fixed locations, the values for receptor locations are computed by interpolation.

Outputs – What You Will Get Out of the Program

The XOQDOQ Report contains several sections:

- A recapitulation of the input data
- A Joint Frequency Distribution of the wind data (wind speed and direction by stability class), along with some additional wind statistics
- Chi/Q for each decay/depletion case in the release at specified distances for each direction from the plant
- Chi/Q for each decay/depletion case in the release at specified distance ranges for each direction from the plant
- DOQ for each depletion case in the release at specified distances for each direction from the plant
- DOQ for each depletion case in the release at specified distance ranges for each direction from the plant
- A summary for each receptor with the Chi/Q value for each decay/depletion case and an overall DOQ
- For 100% elevated releases, the maximum Chi/Q value in each direction from the plant

Available Applications

Several versions of the XOQDOQ program were available for mainframes and minicomputers, including customized versions at different sites.

The standard version of the program has been converted to run on current PC's and is available from RSICC as XOQDOQ32.exe, a component of the NRCDose suite of programs (see references). This program may be used directly, through the NRCDose interface, or through a custom interface.

Directly

Old card file images, or edited version of these images, can be copied to the XOQ_INP.dat file in the NDOSE directory. When the XOQDOQ32.exe program is started, it will create an XOQDOQ output file named XOQ_OUT.dat in the same directory. The following is a sample input file.

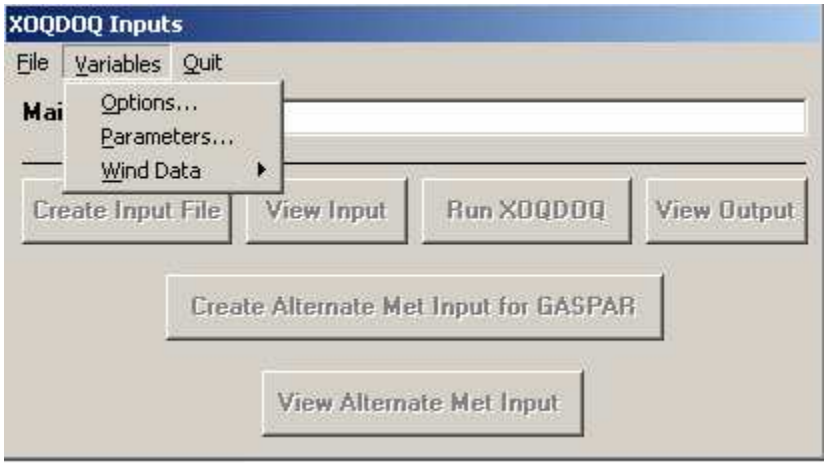
```
00000001000
Demonstration of Input Format
    6    7    0   15    5    3    0
   60  101 2.26   -8    0

    0    0    1    0    1    0    1    1    0    0    0    1    0    0    0    0
    5    1    2    2    5   25   56   64   34   11    5    0    0    0    1    4
   13    3    0   58   13   43   71   65   67   57   16    0    1    6   14    6
    3    1    0   92   14   36   43   66   87   52    8    0    0    1   20   14
    0    0    0   20   10   27   65   61   67   25    1    0    0    2   13    4
    0    0    0   36   79  165  136   88   85   33    0    0    0    0    2    1
    0    0    0    0    1    0    0    2    0    0    0    0    1    0    0    0
    1    9    1    2    9   13   11    9   16   22    7    1    0    3    5   11
   25    7    2   35   47   28   14   12   20   20    8    2    2    7   17   21
    5    6    1   46   47   34   64   43   51   23    6    1    0    2   19   16
    1    0    2   14   43   33   40   34   36   41    0    0    0    2    6    3
    1    0    0   33   90   87   67   27   35   25    0    0    0    0    2    2
```

```
    0    0    0    0    1    0    5    0    2    0    0    0    1    0    0    0
   10    7    2    7   19   20   11    5   18   21   18    6    6    3   10    9
   46   12    6   31   83   50   29   21   25   34   19    5    0   23   29   29
   26    9    3   63   85   57   79   50   56   48   11    0    0    6   38   29
   10    0    1   22   61   43   54   44   29   28    9    0    0    0    6    7
    1    0    1   64  124  105   45   19   40   34    0    0    0    0    8    4
    8    6    7    8   11   13   17   11   14   13   15   16   12    9    9   12
   57   52   33   49  114   60   49   57   58  115  158   79   73   91  100   81
  245  259  104  201  253  129  111   90  136  160  234   73   85  147  262  223
  410  291  274  339  276  187  153  136  111  263  161   12   31  193  541  264
  108   16   79  190  248  135  118   69   44  135   38    0    1   39  199  111
   16    3   18  275  395  229   82   35   68   87    3    0    0    2   60   53
    9   13   14   15   11   13    7    9   18   14   19    9    7   16   10    4
   41   32   57   82   91   45   26   33   44   44   71   75   54   37   35   45
  149  143  123  257  124   32   23   27   37   43   65   36   44   89  150  177
  534  322  175  294  120   27   33   17   33   34   25    3   10   58  428  510
  161   29   35  146   64   33   11    8   14   12    5    0    0    6  131  186
    4    1    7  145  102   33    5    4    6   10    1    0    0    0   13   18
    9    7   16   12    9    8    5    7    8    3   12   12    8    8    3    4
   22   19   41   49   29   27   15   13   15   16   22   35   34   21   14   25
   35   40   79   94   43   16    7   11    7   15    8   17   39   38   35   50
  123  111   76   64   26   10    2    5    8    4    1    1    4   18   52  149
   10   10    2   19   10    3    0    6    4    8    1    0    0    0    3   12
    0    0    0   17   11    4    0    0    4    1    0    0    0    0    0    0
   16   16    9   13   14    9    7    9    5   10   16   16   18   12   10   19
   33   50   54   57   24   19   10   13   15   10   28   31   49   26   37   37
   75   59   91   76   21    2    4    4    3    7    0    3   21   32   40   56
  109   45   32   19    6    4    0    3    2    3    0    0    4   14   35   86
    2    0    0    4    5    0    1    0    2    1    0    0    0    0    1    0
    0    0    0    1    8    2    1    0    0    4    0    0    0    0    0    0
  101  3.5  7.5 12.5 18.5 23.5   99
    2    2    2    2    2
Residences
   141126.   141287.
Milk Animals
   151931.   164184.
Meat Animals
   153540.    12574.
Gardens
   141287.   161931.
Populations
   131448.   162735.
Plant Turbine Building
15.75 1.92 52.4 49.6 1973 52.4    0
A        0    0    0
Plant Rad Waste Building
10.16  1.4 33.8 32.9 1304 33.8    0
B        0    0    0
Plant Reactor/Refuel Building
13.72 2.41 52.4 49.6 1973 52.4    0
C        0    0    0
```

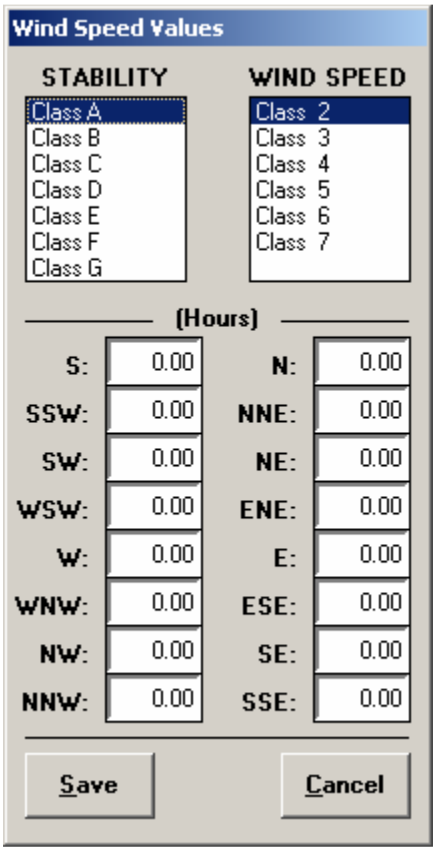
XOQDOQ Input Sample

NRCDOSE Interface

A simple interface is included with the NRCDOSE suite. It provides a very basic graphical user interface to the XOQDOQ program, but is not very advanced in data input (particularly wind data) and managing the input parameters.



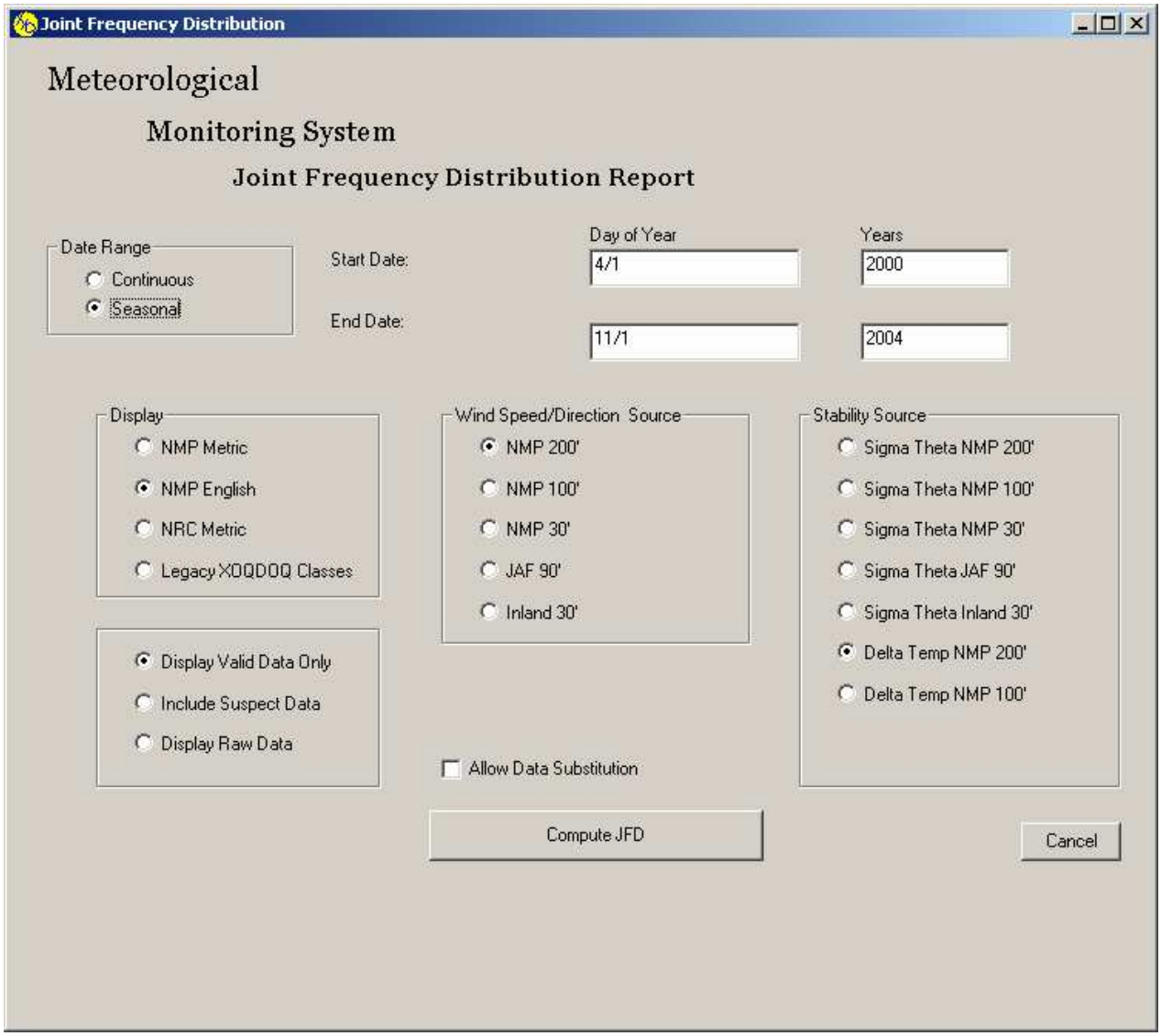
Sample Screen from NRCDOSE Interface



Wind Data Screen from NRCDOSE Interface

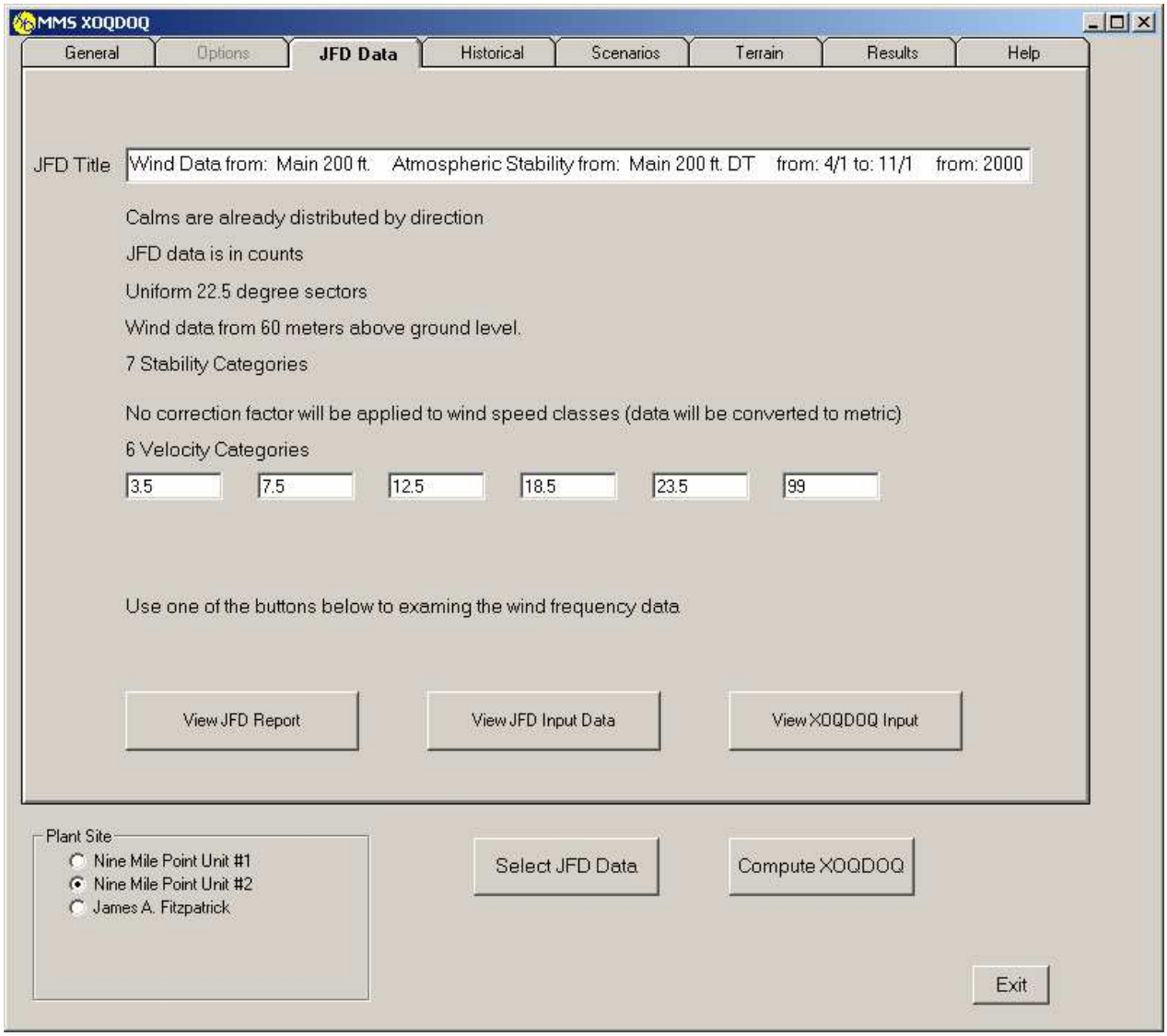
Custom Interface

The more convenient choice is creating a custom interface that can extract wind data from a plant's database or file archives, manage release and receptor scenarios and output files, and run the XOQDOQ engine.



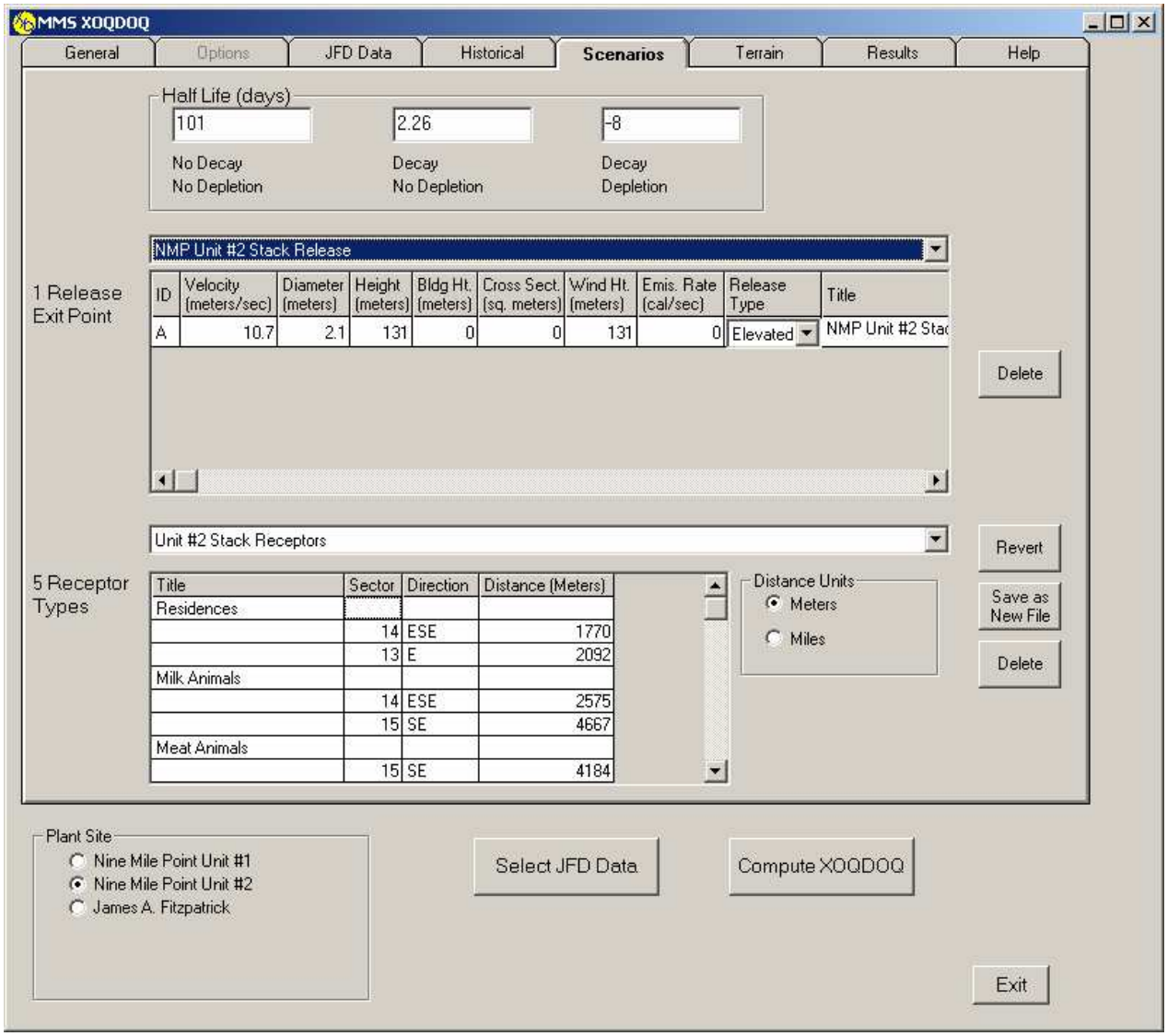
MMS Interface – JFD Selection Screen

Referencing the plant's wind database or archive files permits rapid selection of continuous or seasonal data, at appropriate wind heights for the release.



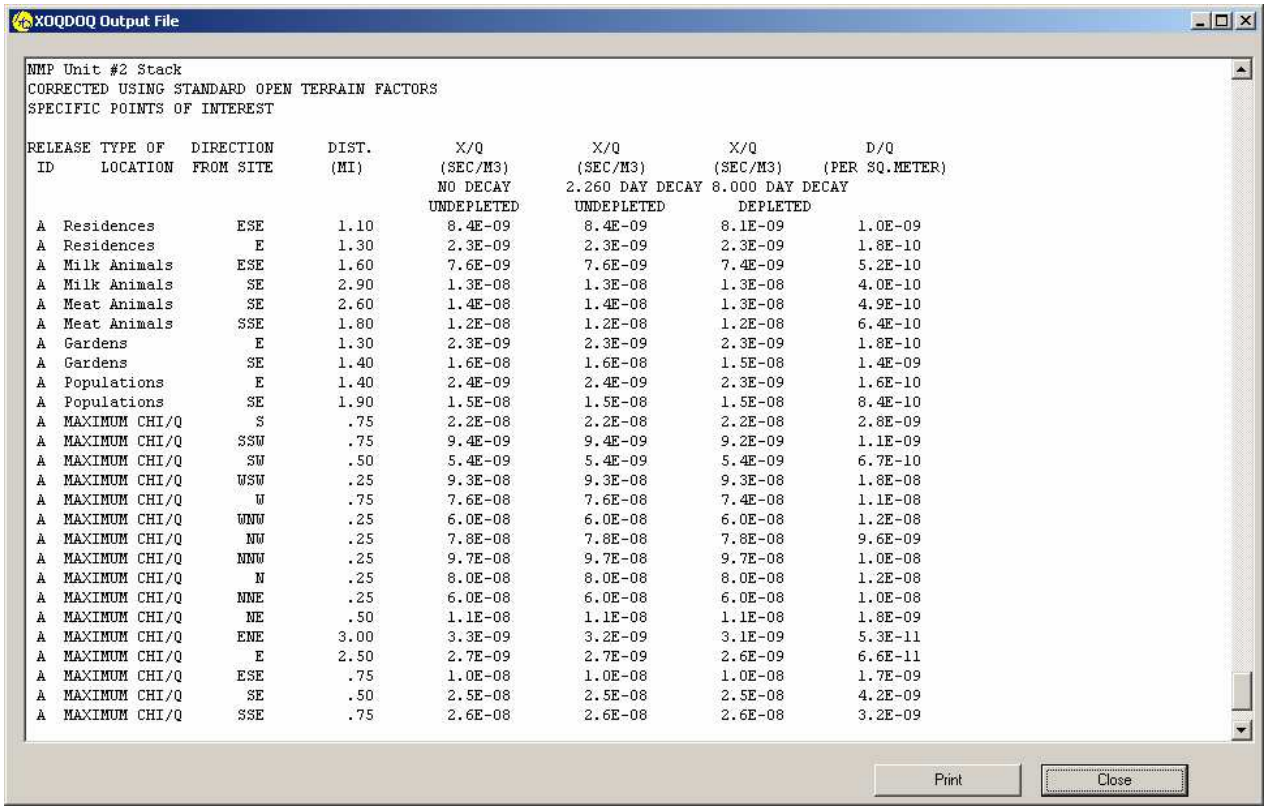
MMS Interface – JFD Data Summary

The interface program can automatically set the wind input options, such as number of stability categories, velocity categories and maximum wind speed per category. It permits the easy selection of historical wind data sets for comparison purposes or test data sets for analytical purposes.



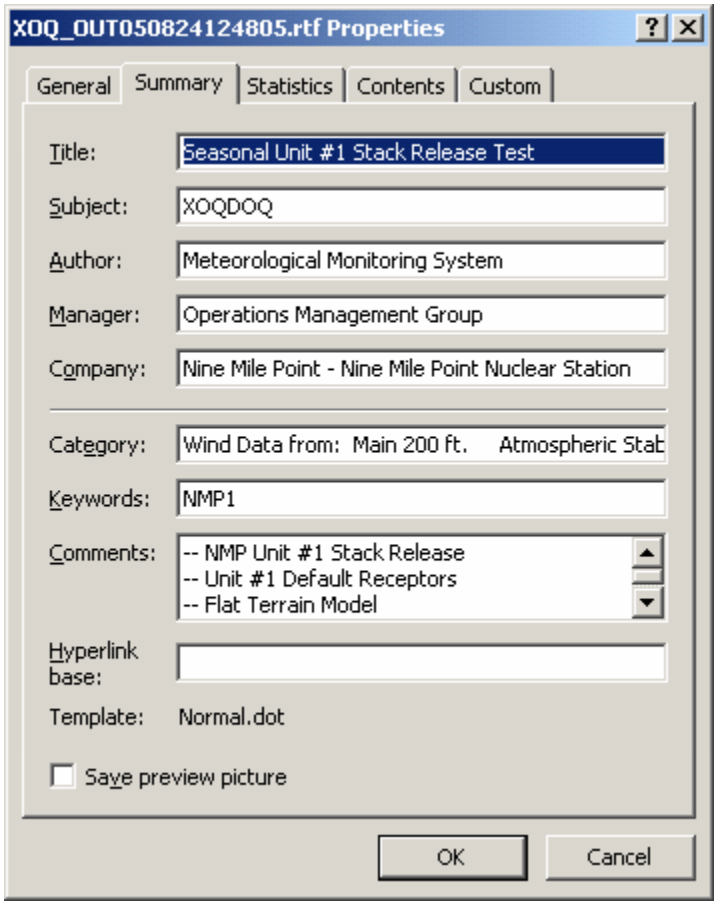
MMS Interface – XOQDOQ Scenario

An interface program can manage release and receptor scenarios, allowing the user to easily select a set of receptors that matches the release. It also provides a way for data to be entered in different units and then automatically converted to acceptable input for the XOQDOQ engine. It can simplify the entry of certain options, such as selecting the type of release.



MMS Interface – XOQDOQ Output View

An interface program can manage the output files, converting the FORTRAN carriage control characters to Microsoft Word compatible format, correcting some of the XOQDOQ engine errors. It can simplify naming and copying of the resulting files and can also attach properties to the output such as a summary of the datasets used in generating the report.



Properties Form

Pitfalls

While a rewriting of the XOQDOQ code would be advantageous for removing some of the inconsistencies mentioned below, a rewrite would require revalidation, etc., with its own set of problems. There are some limitations, inconsistencies and irregularities in the existing version that will remain until this is done. Some of these problems may be ameliorated by the use of an interface program or pre- or post-processing tools.

- Multiple previous versions
  Existing XOQDOQ results may have been generated on a customized version of the old XOQDOQ program. Old input files may produce different results or even fail if rerun with the new PC program.

- Inconsistent use of engineering units
  For example, the XOQDOQ engine takes input in meters for specifying receptor distances, but outputs the resulting XOQ and DOQ values in miles from the source.

- The required format of wind data
  (which may be counterintuitive to users of other meteorological programs)
  Most applications deal with wind data presented starting at wind from the North and proceeding clockwise East to South to West and back to North. The XOQDOQ program expects data beginning with wind from the South.

- Arcane input options
  Several input options are based on tricks common to FORTRAN card-based systems. Some examples:
  - Elevated releases are indicated by negating the Stack Height Value

- A Ground Release is specified by setting the velocity and diameter entries to 0 and wind height entry to 10 meters
- Any other combination is treated as a mixed release

- Inconsistent terminology (both X/Q and CHI/Q are referenced in the output report)
- Wind height must be set to vent height due to an existing program bug
- Errors in the formatting of the report

References

XOQDOQ: Computer Program for the Meteorological Evaluation of Routine Effluent Releases at Nuclear Power Stations, NUREG/CR-2919, September 1982

X/Q and D/Q Tables for Nine Mile Point Unit 1, Nine Mile Point Unit 2 and James A. Fitzpatrick Nuclear Power Plant, Chas. T. Main Inc., November 1985

RSICC Code Name: NRCDose, Code Number C00684, latest version 2.3.8, Radiation Safety Information Computational Center of the Oak Ridge National Laboratory, http://rsicc.ornl.gov
(Contains XOQDOQ, GASPAR II & LAPTAP II)

Acknowledgements

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Drexel University and the Gateway Engineering Education Coalition, for the plume graphics. An online tutorial with an introduction to plume computations is available at http://www-gateway.vpr.drexel.edu/files/Webbased_Environmental/gateway/ce752/default1.htm