Assessment of the Impact of Annual Variations in Meteorology on Individual and Population Doses

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ABS Consulting has for the last 40 years collected meteorological data at nuclear power plants and used that data to calculate dispersion parameters for use in licensing, routine annual reporting, and accident calculations. In the early days of this data collection there was considerable variation in the quality of the data that could lead to wide swings in the dispersion factors calculated. But now the quality of data is much better. This leads to several questions concerning how much data is enough to use in making these calculations and the differences between using hourly data and annual average dispersion factors in calculating individual and population doses. It is sometimes assumed that a single year of meteorological data is sufficient to characterize a site, and that data reduced to average X/Q data can be substituted for hourly data without materially changing the results. In this study, the authors used data collected for periods of 10 years or more at six sites to statistically assess the following cases:

1. *The differences between annual datasets when examining the dose at given locations in the population grid using joint frequency tables of meteorological data.*
2. *The differences between annual datasets when examining the dose at given locations in the population grid using hourly meteorological data.*
3. *The differences between doses using joint frequency tables and hourly meteorological data at the same locations in the population grid for the same years.*
4. *The differences between annual datasets when examining total population dose using joint frequency tables of meteorological data.*
5. *The differences between annual datasets when examining total population dose using hourly meteorological data.*
6. *The differences between total population doses using joint frequency tables versus hourly meteorological data for the same years.*
7. *The effects of using actual population data rather than an average population density on the variations of total population dose.*

Results will show whether there are systematic differences between using joint frequency tables and hourly meteorological data, the extent and significance of such differences, and the degree of variation to be expected between years. We will make recommendations concerning the use of hourly meteorological data versus annual average dispersion factors and the number of years of data to use in order to reduce the variation in dispersion factors.

I. INTRODUCTION

When radioactive material is released into the atmosphere, it is transported by the ambient wind and simultaneously dispersed by turbulence in the air. When a continuous release occurs a plume is formed in the downwind direction. The random-walk nature of the dispersion tends to give the concentration profile a Gaussian shape in both the vertical direction and the horizontal direction transverse to the wind. The relative concentration, denoted χ/Q, is inversely proportional to the product of the wind speed and the plume size in the transverse and vertical dimensions and has units of s/m^3. Radiation dose from direct exposure and inhalation are directly proportional to χ/Q. Thus, the variation in χ/Q can be used as a stand-in for the variation in direct exposure and inhalation dose from the release.

Some of the material in the passing plume deposits on the ground as it passes. The ground concentration relative to the release rate is denoted D/Q and has units of m^{-2}. Radiation dose from ground exposure and ingestion of foodstuffs produced on the land are proportional to D/Q. Thus, the variation in D/Q can be used as a stand-in for the variation in ground exposure and ingestion dose from the release. Deposition can either be dry, from gradual settling of particles, or wet, by material washing out of the plume from rain. Only dry deposition is considered in this paper.

The dimensions of the plume at any point downwind from the source depend on the distance from the source and the atmospheric stability, which measures how quickly turbulence spreads the plume. Stability is classed from A to G depending on the lapse rate, or the change in temperature of the atmosphere with height, with A being very unstable and G very stable. Experimentally-determined plume size models as a function of downwind distance and stability are well-documented[1] and are used, along with the wind speed and direction, to calculate χ/Q and D/Q values at any desired set of locations.

I.A. Calculational Methods

When computer calculations were relatively expensive, the computer codes that were developed to calculate χ/Q and D/Q values used data that was grouped into bins by wind direction (using a 16 point wind rose), wind speed, and stability class. This binned data is referred to as a Joint Frequency Table (JFT). Calculations were performed once for each bin, and weighted by the number of hours in each bin to calculate the results. The NRC code XOQDOQ[2] falls into this category. In this paper, we used the code MIDJFNET[3] to calculate JFTs.

Computer codes were subsequently developed that calculated the same type of average values using the same formulas, but using the actual wind direction and speed for each hour during a period of at least a year, or possibly multiple years. The ABS Consulting Code XDCALC[4] can produce results based on hourly computations.

There are many other variations in how χ/Q and D/Q values can be calculated, but it is possible to run XOQDOQ and XDCALC in such a way that the differences in the results are solely caused by the differences between JFT based calculations, and those done using hourly data.

I.B. Questions of Interest

The first question of interest is whether results calculated using a JFT differ significantly from those calculated using hourly data when the underlying meteorological data is the same. Use of hourly data would be expected to give greater fidelity to the underlying meteorology, and if the results using JFT data differ significantly from those resulting from hourly data, the use of JFT data should be avoided.

The second question is how much variation results when comparing different years of meteorological data. If the variations are small, one year of data will be sufficient. If they are large, the use of multiple years of data will significantly reduce error.

Year-to-year changes in meteorology can change which areas are affected more in different years, but the total population dose is expected to vary less than the variations at an individual location, as all activity released will affect some locations. Thus, another question of interest is how the variation in population dose compares to the variations at individual locations. Another question is how much of this is due to correlation between population distribution and meteorology, and if these variations are due to similarities between population distribution and meteorology. This can be determined by comparing the actual population to a uniform population of the same size.

All of these questions apply only to radiation doses resulting from routine releases taking place more-or-less uniformly during the year. The composition of such releases will have some effect, particularly regarding whether deposition plays a large part in the dose pattern. On the other hand, doses resulting from large accidents are highly dependent on the meteorological conditions at the time of the accident and thereafter, and the changes in the consequences of such accidents cannot be determined from average meteorology.

II. DATA ANALYSIS

Meteorological data from six plants scattered across the United States was analyzed. The number of years varied at different plants, from five to fourteen years, with a total of 56 plant-years of data examined. Typically, the XDCALC and XOQDOQ codes would be run and results compared using meteorological data from the same years. For XOQDOQ, the data would be converted to JFT data first. The variation between different years could also be compared using the same results. Runs of the same codes using data combined into data sets with lengths from two years to five years was used to examine the effects of using multiple years. Finally, population data (from the USNRC SECPOP2000[5] Code) was combined with the calculated χ/Q and D/Q values to examine the effects of the different variations on population dose. Data from only two of the sites with nine and fourteen years of data were used as examples in this paper.

III. Results

III.A. Use of Hourly vs. JFT Data

Data from Site 6, located in the Southeastern United States, was analyzed from 2007 to 2015. Annual runs were made with hourly meteorological data using XDCALC, and with XOQDOQ using JFT data. The calculated average χ/Q values at each location were compared at ten distances in the sixteen standard directions for each year, and for the average over 9 years. On average, the XDCALC gave values higher by a factor of 1.22±0.05. Even with the overall calculational bias removed, there are marked differences in the two methods in both direction and distance. These results are shown in Figure 1.

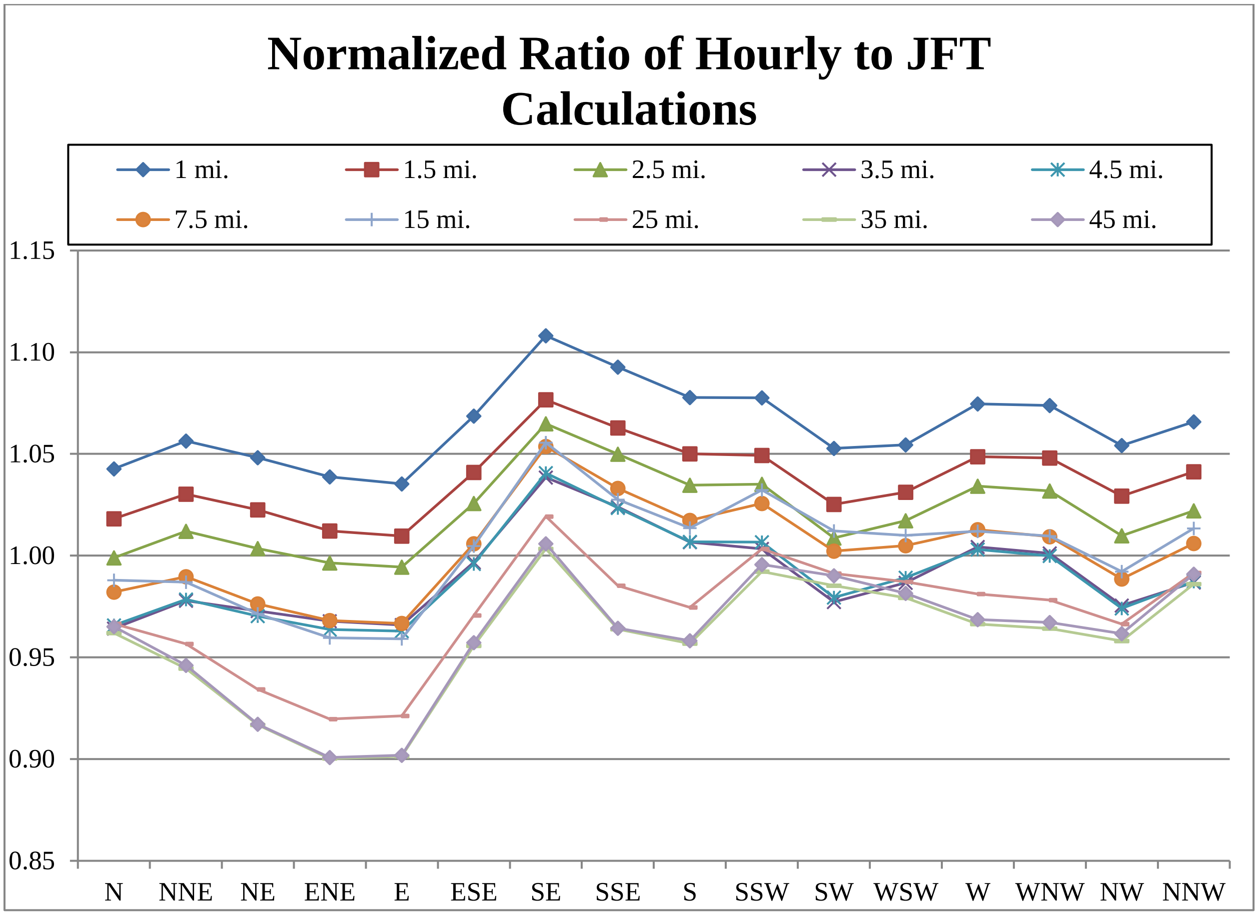


Fig. 1. Normalized comparison of a nine year average of χ/Q results for hourly and JFT calculations.

III.B. Importance of Annual Variations

III.B.1. Annual Variations in Peak χ/Q Location at the Site Boundary

Annual variations in χ/Q values are important in a number of contexts. One of these is the selection of the peak χ/Q value and direction at the site boundary. For this calculation, the site boundary was assumed to be at a distance of one mile in all directions. In this case we looked at XDCALC values only, and examined the results, again at Site 6, for the years from 2007 to 2015, and the average over those years. The results are shown in Figure 2, with the average shown as a dotted line. While the correct location for the peak (ENE) would be chosen in most years, for several years NE would be chosen instead. The standard deviation is about 15% of the mean value, even if the correct value is chosen.

III.B.2. Annual Variations in χ/Q and D/Q Values

As mentioned in the introduction, the value of χ/Q can be used as a stand-in for noble gas and inhalation doses, while D/Q can be used as a stand-in for ground plane and ingestion doses. The variation of these quantities was examined at Site 1, located in the Northeastern United States using results from XOQDOQ. In this case the measure used was the ratio of the standard deviation to the mean of χ/Q and D/Q values at each of the 160 points in the grid. The results are shown in Figure 3 with χ/Q on the left and D/Q on the right. There is a sharp peak toward the north, which is caused by much higher values in this direction in 2015 than in other years. There is very little variation by distance; nearly all is related to direction.

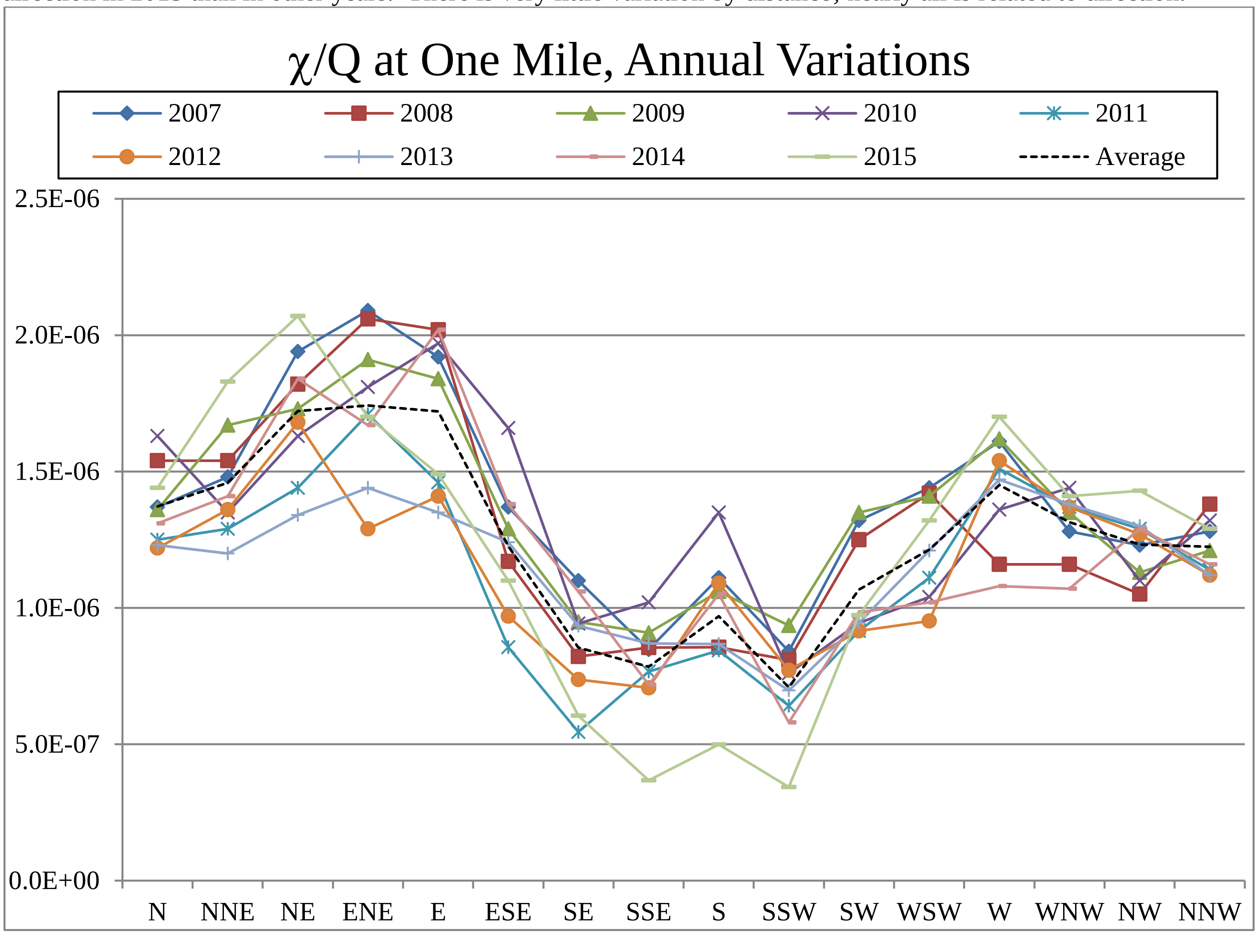


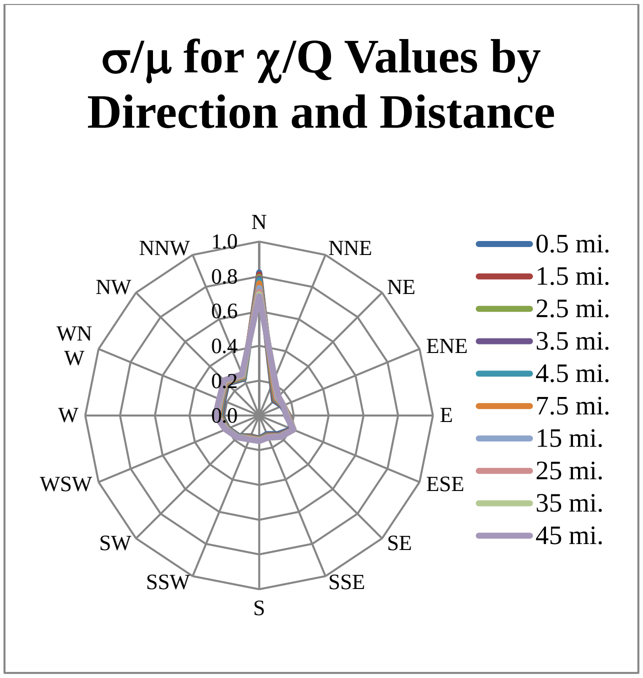
Fig. 2. Annual Variations in χ/Q at One Mile at Site 6.

III.B.3. Effect of Using Multiple Years of Data on Variations in χ/Q and D/Q Values

The results of the previous section show the effects of a single anomalous year on doses could make them as much as four times the mean value in a particular direction. Figure 4 looks at the same site using annual data, and also data comprising 2, 3, and 4 sequential years, always including the anomalous year. The size of the peak to the north is reduced by a factor of two by using four years of data.

III.C. Variations in Population Dose

The effects of annual variations on population dose were examined by taking the product of the number of people in each of 160 grid elements and the χ/Q (for air doses, either noble gas or inhalation) or D/Q for ground doses (either ground plane dose or ingestion dose), and summing the result. This was done for the actual population at the site, as determined by SECPOP2000, and also for a uniform population density with the same population. The results for both air and ground dose were normalized to the average for the uniform population density. These results are from Site 1, and used XOQDOQ



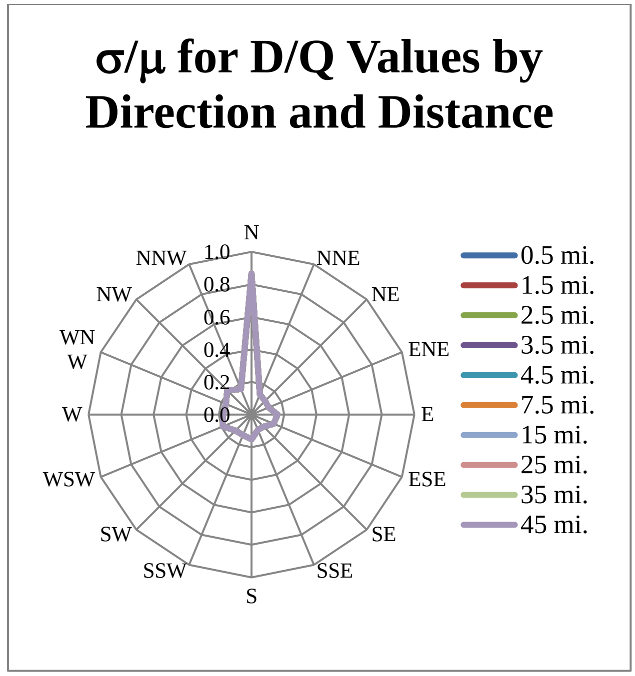


Fig. 3. Ratio of Standard Deviation to Mean χ/Q and D/Q Values for 14 Years of Data at Site 1.

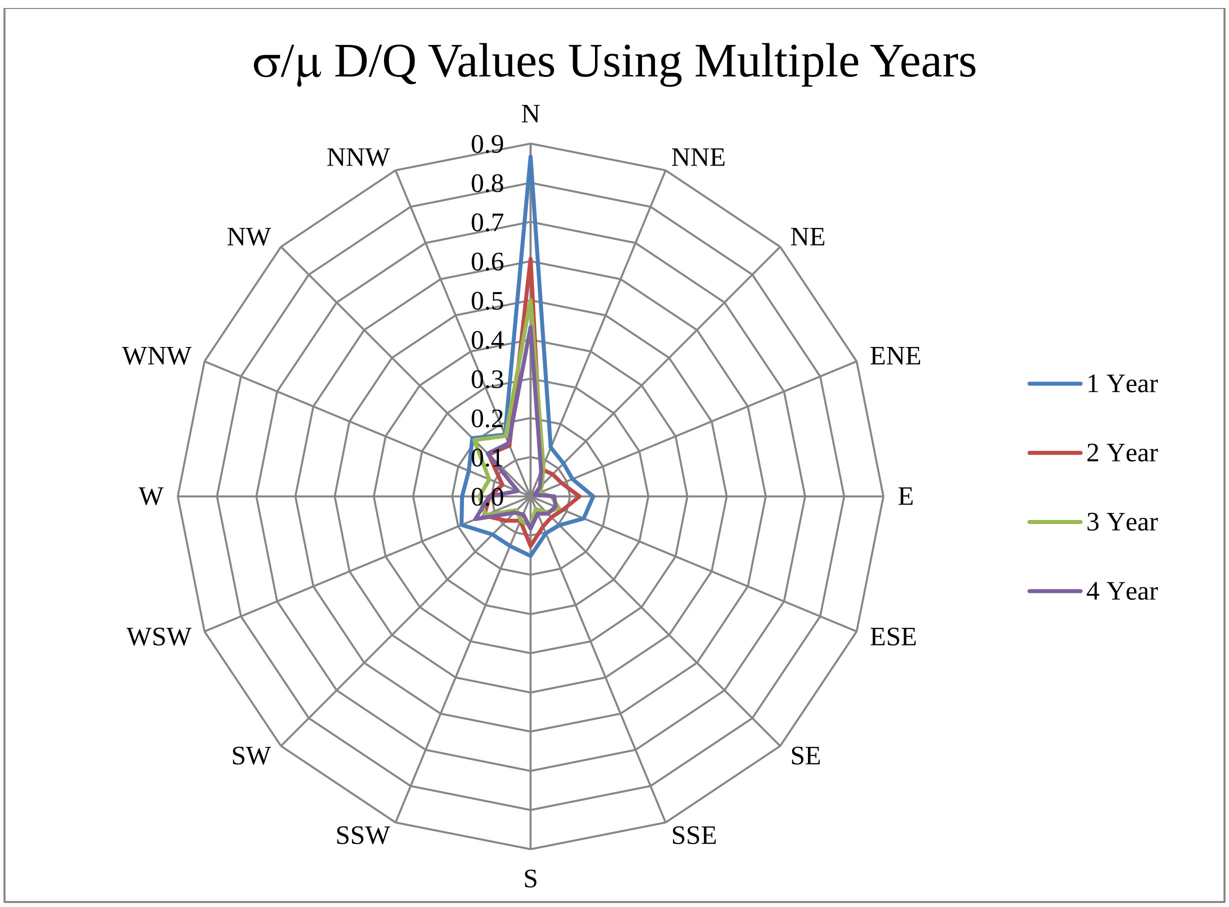


Fig. 4. Ratio of Standard Deviation to Mean D/Q Values Using 1, 2, 3 and 4 Years of Meteorological Data

calculations. The results are shown in Figure 5. The air dose shows considerably more annual variability than does the ground dose. The ratio of the standard deviation to the mean is 13.0% for air dose using actual population, 11.5% for air dose using uniform population density, 5.1% for ground dose using actual population, and 0.0% for ground dose using uniform population density. If three years of meteorological data is used instead of a single year, the values are reduced to 9.1%, 6.5%, 2.1% and 0.0% respectively. If five years of meteorological data is used, the values are reduced to 6.5%, 4.3%, 1.7% and 0.0% respectively.

The use of actual population gives significantly more accurate dose than does a uniform population. In this case, the uniform population density overestimates air doses by about 25.0% and ground doses by about 15.8%. The magnitude and direction of this effect can be expected to be highly site-dependent.

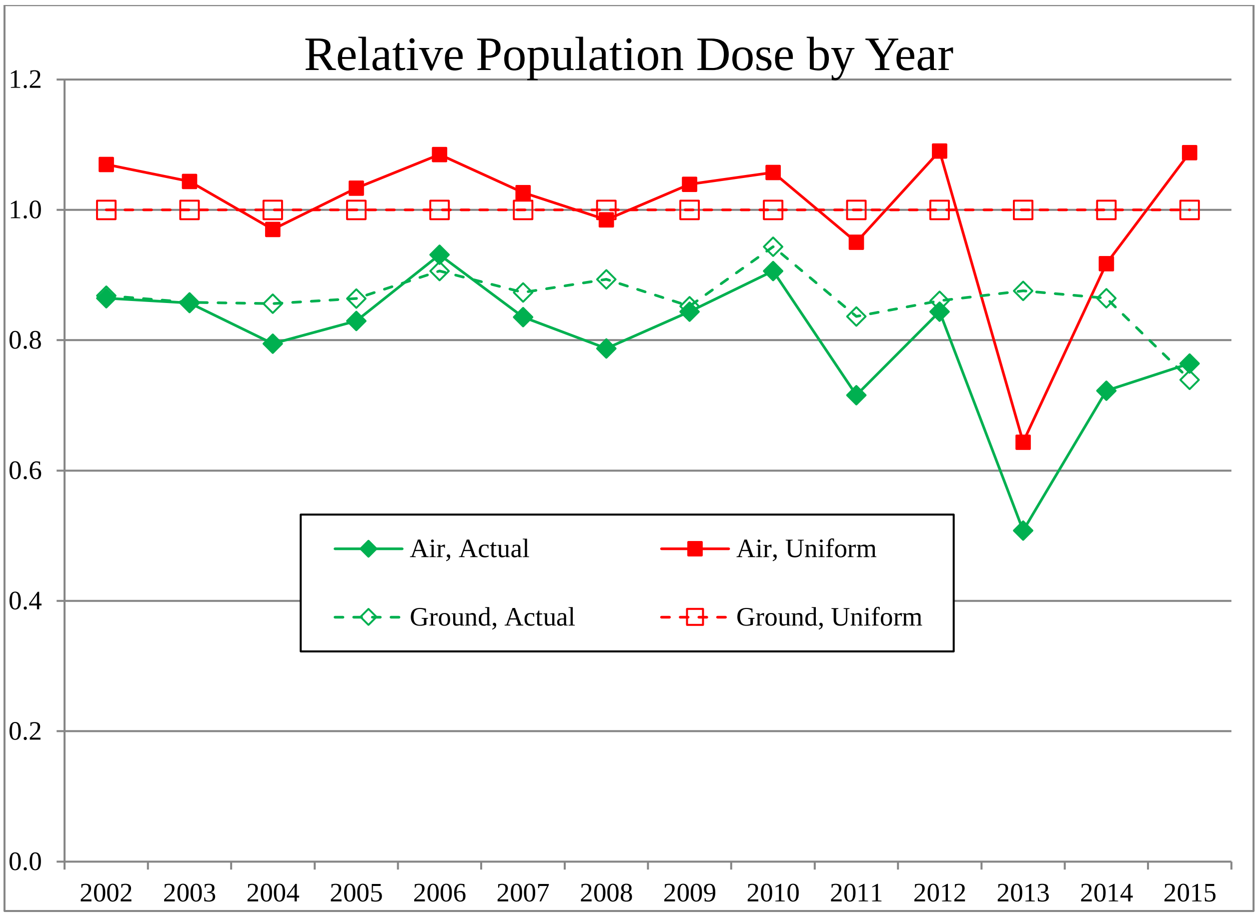


Fig. 5. Annual Variations of Relative Population Dose.

IV. CONCLUSIONS

The doses calculated for routine releases have a significant dependence on the year or years from which the meteorological data is taken. There is somewhat less effect from whether the calculations are performed using hourly data or data binned into Joint Frequency Tables. Estimates of doses at a particular location can be highly dependent on the year chosen if a single year of meteorology is used, and this dependence tends to be highly directional. However, population dose is also dependent on the year or years chosen. Use of meteorology from multiple years reduces this variation significantly. We recommend the use of at least three years of meteorological data, and five years if possible. The use of actual population data rather than a uniform population density can have a large impact on population dose. In the case examined here, it was about 25% for air dose and nearly 16% for ground dose.

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