Atmospheric transport of Radio pollutants from Reactors

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Source CNN
https://www.cnn.com/2023/04/11/us/richmond-indiana-recycling-plant-fire/index.html

RECENT ACCIDENT

INTRODUCTION

- All operating nuclear power plants are required to collect hourly Joint Frequency Distribution (JFD) data for atmospheric wind direction, wind speed and stability class,.
- This information is a critical piece of the Annual Radioactive Effluent Report(1) to the Nuclear Regulatory Commission (NRC) to demonstrate compliance with federal regulations.
- Callaway maintains two on-site Meteorological Towers (Met.T) to collect hourly data for wind speed, wind direction, air temperature, atmospheric stability, and Dew point/relative humidity at two heights; 10 m and 60 m above ground level to assist the facility in demonstrating regulatory compliance.
- It is desirable to supplement and augment this data from other sources (regional and national resources). Unfortunately, formats, frequency and naming conventions across these multiple data sets are inconsistent.

OBJECTIVE

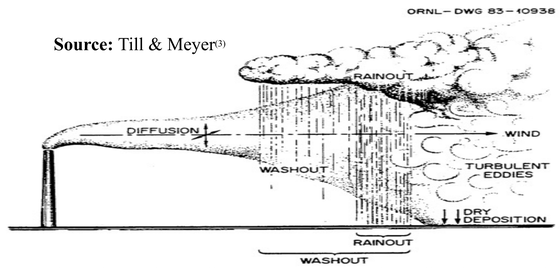
- Supplement meteorological data for a nuclear facility by data mining and synthesis from surrounding weather stations.
- Gaussian plume model is commonly used for estimating pollutant spread from the stack,

$$\Psi = \frac{Q}{2\pi\bar{u}\sigma_y\sigma_z} exp\left[-\frac{y^2}{2\sigma_y^2}\right]\left\{exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right]\right\}$$

Q = release rate, $\bar{u}$ = wind speed, H = effective stack height, σ = dispersion coefficient

- Plume spread is highly dependent on dispersion coefficient (σ_y and σ_z).
- Dispersion coefficient in turn depends on atmospheric stability which is indirectly measured at the nuclear facilities but not typical recorded at any weather station or airports.
- Atmospheric stability determines turbulence intensity and diffusion processes that affect the mixing of effluents into the atmosphere(2).

Source: Till & Meyer(3)



- Airports and weather stations collect data on wind speed and direction, but a clear definition of stability is not readily available for those locations.
- Therefore, an inference is required to extract stability class from available data for example, wind speed, temperature lapse rate and cloud cover etc. at airports and weather station using Vogt alternative of stability classes.
- ***Goal of this project is to -***
  - ***Develop correlation for wind velocity and direction between nuclear facility and weather stations.***
  - ***Develop techniques to infer atmospheric stability for weather stations.***
  - ***Development correlation for atmospheric stability between nuclear facility and weather stations.***

Stability Measurement Methods

- Literature discusses how to infer atmospheric stability from meteorological observations(2).
- Most weather stations are collecting wind direction & velocity but atmospheric stability.

Methods	Parameter Needed
Pasquill Stability	Surface Wind Speed (10 m), Daytime Insolation, and Nighttime Conditions
McElroy et al	Richardson Number, and Standard deviation of horizontal wind fluctuation.
Vogt alternative of stability class	Synoptic observation, sun height, degree of cloudiness, wind velocity (m/s)
By vertical temperature difference	Lapse Rate
By standard deviation of horizontal wind direction	Wind direction fluctuation (deg)
Relations between Pasquill type & turbulence criteria Ri & L for flow over short grass	Richardson Number, and Monin & Obukhov length

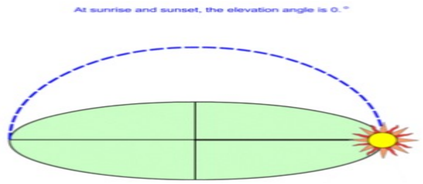
CALLAWAY'S METHOD FOR CALCULATING ATMOSPHERIC STABILITY

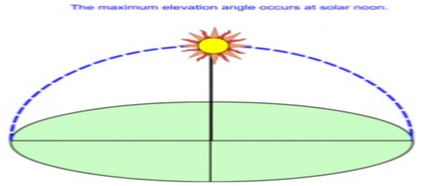
- Callaway uses the vertical temperature difference (ΔT) for stability estimation.
- Temperature lapse rate measures vertical temperature variation direction and is generally reported in degree Celsius per 100 meters.
  - For example, if $^{\Delta T}/_{\Delta Z} \geq -1.9$, *the stability class will be extremely unstable* **(A-class)**
    and if $-1.9 > {}^{\Delta T}/_{\Delta Z} \geq -1.7$, *the stability class will be moderate stable* **(F-class)**

ATMOSPHERIC STABILITY INFERENCE FOR WEATHER STATION

- Use Vogt's alternative of stability class estimation which focuses on the use of synoptic observation/calculations, sun height angle, degree of cloudiness, and wind speed (at 10 m for flat terrain and 20 m for area surrounded by trees).
- To determine the sun height angle/sun elevation angle, which is the angular measurement of the sun height in the sky from the horizontal, we need to know the day of the year and the time of the day. This information is used to calculate the amount of solar energy that the Earth's surface receives.

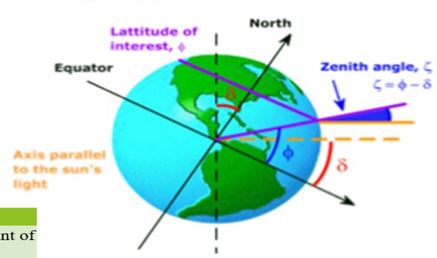
Sun Elevation Angle (4)



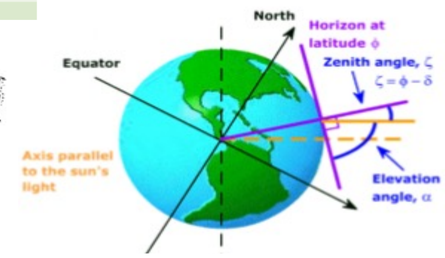


- The sun elevation angle was determined by;
  - $\alpha = sin^{-1}[\sin\delta \sin\varphi + cos\ \delta \cos\varphi\ cos(HRA)]$
    - Latitude (φ)
    - Declination Angle (δ)
    - $\delta = -23.45^0 \times \cos\left(\frac{360}{365} \times (d+10)\right)$
    - d days since the start of the year
- Hour Angle (HRA) either solar time conversion

The zenith angle, ζ, at solar noon is defined as the angle between the incident sunlight and the particular location and is given by $\phi - \delta$.



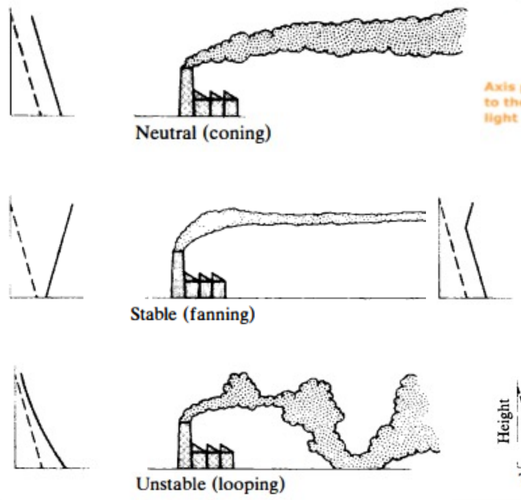
The elevation or altitude angle, α, is defined from the horizontal plane and is given by 90° – the zenith angle, or 90° – (ϕ – δ)



Contractions for Sky Cover

Reportable Contraction	Meaning	Summation Amount of Layer
VV	Vertical Visibility	8/8
SKC or CLR	Clear	0
FEW	Few	1/8 – 2/8
SCT	Scattered	3/8 – 4/8
BKN	Broken	5/8 – 7/8
OVC	Overcast	8/8

Atmospheric Stability & Plume Behaviors (3)



Classification of Atmospheric Stability

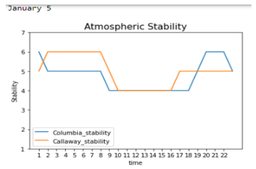
Atmospheric Stability Categories			
Categories	Letter	Number	Image
Extremely Unstable	A	1	
Moderately Unstable	B	2	
Slightly Unstable	C	3	
Neutral	D	4	
Slightly Stable	E	5	
Moderately Stable	F	6	
Extremely stable	G	7	

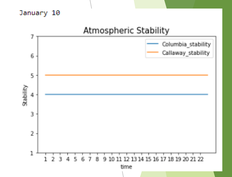
DATA NEEDS

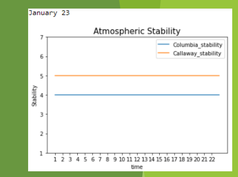
- High temporal and spatial resolution, cloud cover data from sources such as,
  - Atmospheric Science Data Center (ASDC)
  - Atmospheric Infrared Sounder (AIRS)
  - Light Detection and Ranging (LiDAR)

RESULTS

- At Columbia Regional Airport, St. Lambert International Airport, and Jefferson City Memory Airport, the hourly atmospheric stability was computed for January, May, and September. These airports were selected based on their proximity to Callaway Nuclear Power Plant, and the months were chosen to account for seasonal variations.
- Considering the amount of data, we chose to present the correlation between Callaway Nuclear Power Plant and Columbia Regional Airport for January 5, 10 and 23 with and without correcting for travel time and wind direction. The selection of these dates was made randomly.

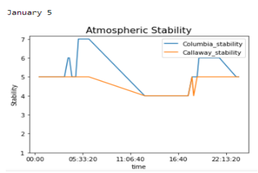


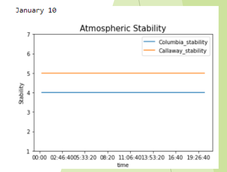


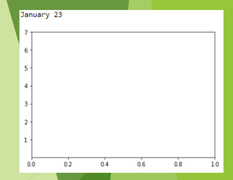


January 5 correlation = 0.60 | January 10 correlation = 0.00 | January 23 correlation = 0.00

- With correcting for travel time and wind direction (NW & W).







January 5 correlation = 0.88 | January 10 correlation = 0.00 | January 23 correlation = 0.00

CONCLUSIONS

- Extraction of atmospheric stability data from cloud cover information using the Vogt alternative of stability classes provided reasonable prediction and correlation with the nuclear station data.
- Travel time correction with the account of the direction in which the plume travel was achieved.
- Height correction for wind speed at Columbia Regional Airport was achieved.
- Results will assist nuclear station and other pollutant sites to better manage their facilities to minimize environmental impact.

REFERENCE

1. Callaway Energy Center 2018 Annual Radioactive Effluent Release Report Revision.
2. Hanna SR, Briggs GA, Hosker RP. Handbook on ATMOSPHERIC DIFFUSION Atmospheric Turbulence and Diffusion Laboratory National Oceanic and Atmospheric Administration This Documaitis.
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ACKNOWLEDGEMENTS

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