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EXTENDED ABSTRACT

Abstract title: Validation of ORCA: A Tool for Radiological Consequences of Accidental Releases

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Introduction

Calculations of atmospheric dispersion and doses following accidental releases of radionuclides to the environment typically rely on the methods in US NRC RG 1.145 [1] or CSA N288.2-M91 [2] which were written for large power reactors with Exclusion Area Boundary (EAB) distances of 3000 feet. There is, however, a general interest in reducing the size of the EAB for new large power reactors and, particularly, for Small Modular Reactors (SMRs). Reducing the size of the EAB requires evaluating atmospheric dispersion and doses in the vicinity of buildings, which introduce unique technical challenges. ORCA (On/Off-site Radiological Consequences of Accidents) was developed to address these technical challenges. Additionally, ORCA evaluates dispersion and doses in the far field (i.e., > 1 km from the source). The code can be used for deterministic and probabilistic safety assessments, emergency planning zone sizing, plant habitability assessments and design assist activities.

Computational Methods and Models

ORCA utilizes probabilistic sampling of meteorological data records to establish the statistical variation of consequences as a function of weather conditions. It accounts for all the phenomena required by the CSA N288.2:19 [3] including: plume rise, downwash, entrainment, plume broadening, mixing height, Thermal Internal Boundary Layer (TIBL), reflection at an elevated inversion, fumigation, plume transport, plume diffusion, wet deposition, dry deposition, plume depletion, cloudshine, groundshine, and inhalation.

ORCA employs Gaussian plume modelling for atmospheric dispersion. For on-site dose calculations within the vicinity of buildings, the parameterization of NUREG/CR-6331 [5] is available. This parameterization was implemented in the ARCON software [5] to support the application of U.S. NRC regulatory guide RG-1.194 [6] for assessing atmospheric relative concentrations for control room radiological habitability assessments at nuclear power plants. More recently, the WinMACCS software has adopted the same parameterization for near-field applications [7]. In addition, draft regulatory guide DG-4030 [8] proposes this parameterization for determining relative concentrations of radionuclides at relatively short distances (10 m to 1200 m) for licensing of small modular and advanced reactor designs. This supports its widespread usage in the nuclear industry for near-field dispersion and dose assessments.

Wet and dry depletion is modelled using a source depletion model. The scavenging coefficients and dry deposition velocities are those recommended by CSA N288.2-M91. Cloudshine doses in the near-field are calculated by applying a correction factor to the semi-infinite cloudshine dose. The correction factor is calculated by numerically integrating the 3-dimensional integral representing the dose rate to the receptor.

More details on the ORCA computation model and methods can be found in [9].

Validation Case Matrix

ORCA was validated in compliance with ASME NQA-1 [10] and CSA Standard N286.7 [3]. Validation exercises were performed for the following end points (i.e., figures-of-merit) of the software:

- Air concentrations,
- Ground concentrations, and
- Individual dose.

Results

To validate predictions of normalized air concentrations (χ/Q), results obtained from ORCA were compared to observations from fourteen full-scale field studies (e.g., [11], [12], [13], [14], and [15]). A total of 1549 comparisons were conducted using 14 datasets (refer to Figure 1). The overall Mean Relative Error (MRE) had a negative value of -0.52, indicating an overall overprediction across all 14 datasets. This corresponds to an accuracy of approximately a factor of 2, which is on the order of the irreducible uncertainty in Gaussian plume dispersion models.

To validate predictions of ground concentrations, ORCA's predictions were compared to measurements from seventeen studies (e.g., [16], [17], [18], and [19]). A total of 298 comparisons were performed to validate the calculations of ground concentrations resulting from wet and dry deposition (refer to Figure 2). When upper bound deposition coefficients were used for ground deposition and lower bound deposition coefficients were used for plume depletion, the ground concentrations calculated by ORCA were conservative with a MRE of -0.10.

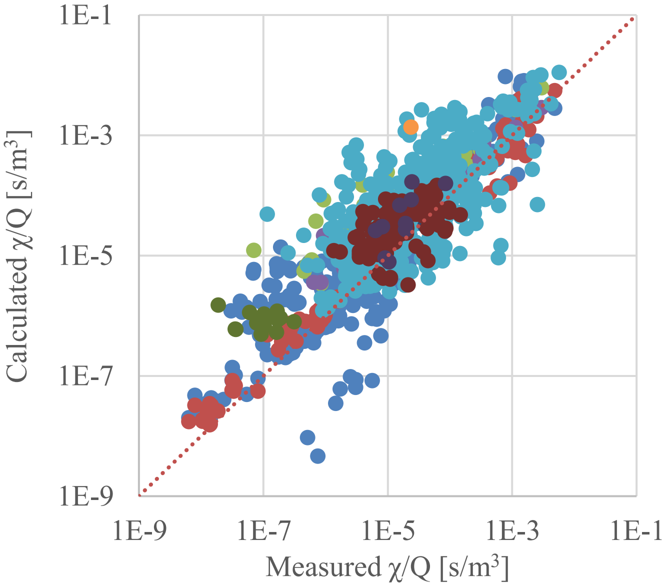

Figure 1: Scatter Plot for Air Concentration Validation

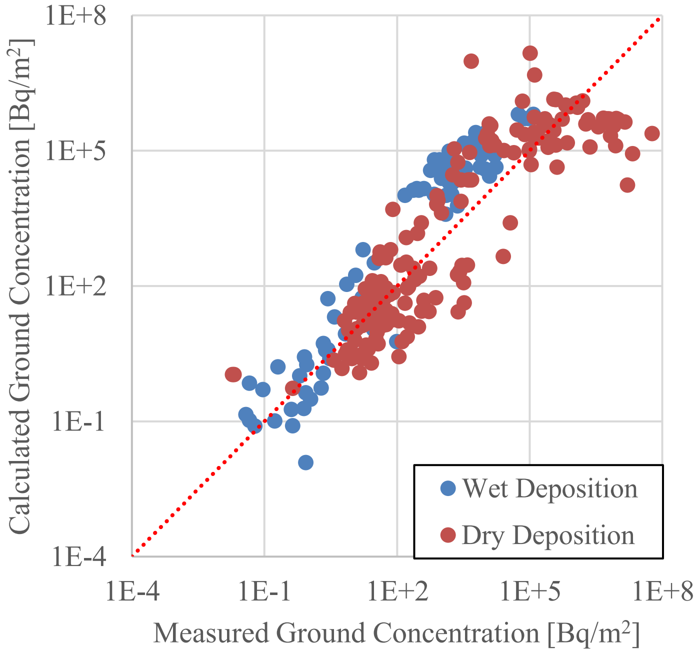

Figure 2: Scatter Plot for Ground Concentration Validation

Validation of individual dose focused on external doses due to cloudshine and groundshine. A combination of experimental data (e.g., [20], [21]), code-to-code comparisons against Monte Carlo N-Particle (MCNP) simulations [22] and benchmark data [23] was used to validate the ORCA cloudshine and groundshine models (refer to Figure 3). The overall MRE of the cloudshine and groundshine models based on comparison with full-scale experimental data was -1.09 and -1.55, respectively, when upper bound deposition coefficients were used for ground deposition.

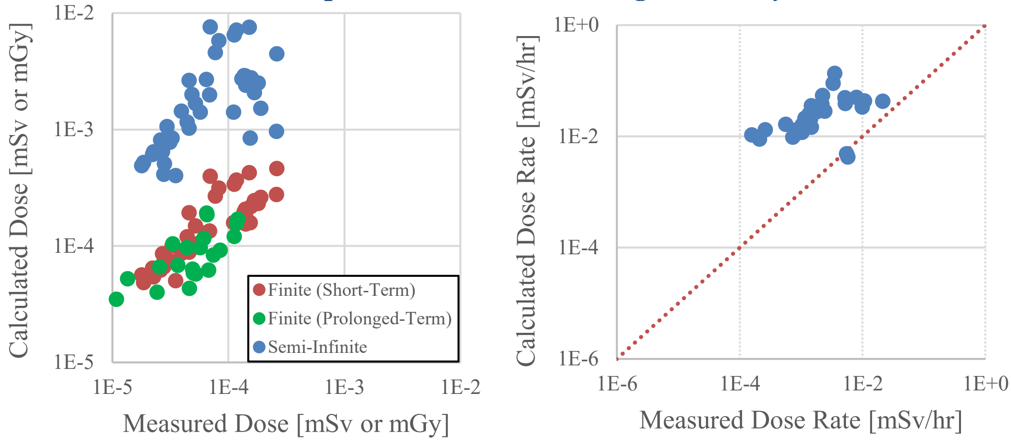

Figure 3: Scatter Plot for Cloudshine (Left) and Groundshine (Right) Validation

Conclusions

The existing tools available in the nuclear industry for estimating of dose to workers or members of public resulting from the accidental airborne release of radiological materials are limited to large power reactors with large EABs. New codes are needed to extend the public dose calculation to new technologies such as SMRs. ORCA was developed to support SMRs in addition to the existing large-scale reactors.

Validation activities required by ASME NQA-1 and CSA N286.7-16 were summarized in this paper. The key end points of the software (air concentrations, ground concentration and individual doses) were validated. ORCA was found to be conservative and fit-for-purpose for safety assessments.

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