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TECHNOTES

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MEDICAL CYCLOTRONS: EVALUATING IMPACTS TO MEET AIR QUALITY STANDARDS

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INTRODUCTION

Medical cyclotrons produce certain kinds of radioactive materials (radionuclides) that can be used for cancer detection, cardiology diagnosis, and medical research. One particular use of cyclotron-produced radionuclides is the Positron Emission Tomography or PET Scanner, which is increasing greatly in use.[1]

Medical cyclotron

During production and use, some of the radioactive material will inevitably become airborne and be emitted into the atmosphere through the building exhaust system. These emissions could pose health and safety risks to the public, including patients and workers at the cyclotron facility. Due to the potential risk to the public, regulations governing radionuclide emissions and dosages have been developed. Therefore, it is important to evaluate the design of exhaust systems for facilities emitting radionuclides, in order to reduce exposure.

This Technote discusses how radionuclide emissions should be addressed in the design of the exhaust system for a medical cyclotron. Discussed below are applicable regulations and analysis methods, plus a few suggestions for the best ways to meet the regulations, without being overly restrictive on the design.

PET Scanner

APPLICABLE REGULATIONS

There are two types of regulations of interest for an exhaust system:

- Maximum Permissible Concentrations (MPC) to be met at the point of exhaust discharge into the atmosphere, and
- Annual Dosage Limits (ADL) to be met at outdoor locations on-site and off-site.

MEETING THE MPC (MAXIMUM PERMISSIBLE CONCENTRATION) REGULATION

MPC limits are published thresholds established by many states for which compliance must be demonstrated (e.g., Michigan, New Hampshire, Massachusetts). The limits vary with the type of radionuclide and can vary from state to state. It is also possible that the facility will desire stricter limits to anticipate easier permit approval or future expansion. The designers should coordinate with the Radiation Safety Officer for the facility to determine the final limits for a project. The officer will typically have experience with state agencies on the written and unwritten permitting requirements.

MPC limit compliance is demonstrated by comparing exit concentrations of each radionuclide against their respective MPC limits. Each radionuclide must be considered separately. Exit concentrations are proportional to the radionuclide emission rates and inversely proportional to the exhaust flow rate. Strategies that can be implemented to meet MPC limits include increasing exhaust airflow rates and/or reducing radionuclide emissions. We recommend reducing emissions over increasing volume flow rate. Increasing flow rate could greatly increase equipment and energy costs.

There are several ways to reduce radionuclide emissions:

- Use particulate filtration, such as high-efficiency HEPA filters, (not effective for gaseous radionuclides, such as C-11 in the form of carbon dioxide)
- Utilize chemical traps
- Insert delay lines within the system to allow for radioactive decay

Radionuclides that are commonly emitted from cyclotrons, such as Fluorine-18, Carbon-11, Nitrogen-13, and Oxygen-15, have short half-lives, in the order of minutes. Thus, containment devices like traps and delay lines are effective in reducing emissions due to the decay that can occur before being emitted to the atmosphere.

MEETING THE ADL (ANNUAL DOSAGE LIMIT) REGULATIONS

The ADL (annual dosage limit) represents the total maximum radionuclide dosage that a member of the general public may be exposed to over a year. Dosages must first be calculated for each radionuclide for the exposure mode selected (i.e., inhalation, submersion, etc.), and then added so that the sum may be compared against the ADL limit. In the United States, the ADL limit is 10 millirems[2] , which accounts for the combined effects of all emitted radionuclides received through the air pathway (inhalation, immersion, deposition on ground and food supplies, etc). Meeting a stricter dosage limit of 1 millirem is often desirable to allow for other existing emissions and future expansion of the facility. An older EPA regulation no longer in force also called for additional reports if predictions were over 1 millirem.

DISPERSION CALCULATIONS

Demonstrating compliance with the ADL limits requires evaluation of atmospheric dispersion of exhaust as well as the exit concentration. Dispersion levels are used to calculate radionuclide concentrations upon which dosages are based. While exit concentrations can be calculated once emissions and flow rates are determined, predicting dispersion of exhaust plumes requires more advanced and complex calculations. Numerical models typically used to predict atmospheric dispersion of emissions from radionuclide stacks include:

- COMPLY (regulatory),
- CAP88 (regulatory),
- SCREEN3 (regulatory), and
- ASHRAE (American Society of Heating Refrigeration and Air Conditioning Engineers).

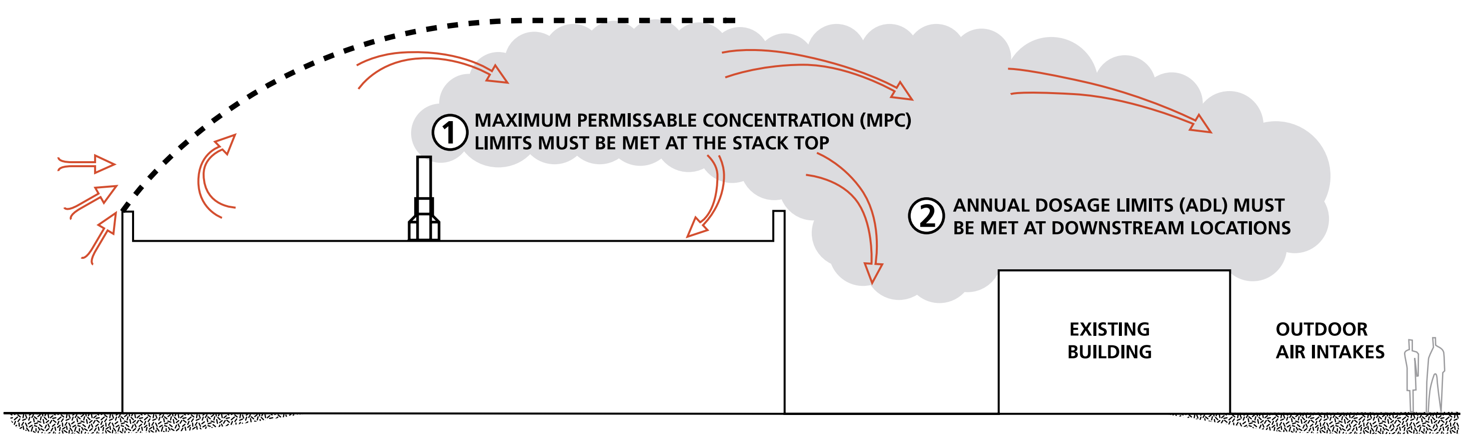


Figure 2: Typical floor elements

The ASHRAE model, which is not prescribed by regulatory agencies but which can be used on a case-by-case basis, is a more accurate numerical model for dispersion around a building or group of buildings. The most accurate procedure to implement in the presence of buildings is wind tunnel modeling. However, wind tunnel modeling is more expensive and should be reserved for cases where numerical models do not provide sufficiently detailed results. Computational Fluid Dynamics is an intensive numerical approach, similar to wind tunnel modeling in scope, which is not recommended for outdoor dispersion modeling. The following table compares the strengths and weaknesses of the various dispersion models. A major disadvantage associated with several of these mathematical models is their high degree of conservatism. The dispersion equations within the COMPLY model are especially restrictive by factors of 10 or more and could unnecessarily restrict emissions and stack design options. A disadvantage to ASHRAE is that some experience is helpful in applying the model to multi-building or complicated building situations. COMPLY needs little experience and will always provide safe (or overly-safe) values.

Comparison of Dispersion Models for Use in Predicting Outdoor Radionuclide Concentrations

Model	Features	Advantages	Disadvantages
COMPLY	Level 4 is the most useful and has several algorithms for dispersion depending on distance and building/receptor configuration. Calculates exposures in mrem/year.	Convenient determination of exposures for various types of radionuclides. Easy to use in the case of dispersion around buildings.	Concentration predictions too high (too strict) for many cases around buildings.
CAP-88 **(Not Recommended)**	Uses standard Gaussian dispersion models assuming a relatively tall stack and no nearby buildings. Better for distant off-site impacts. Calculates exposures in mrem/year and other risk results.	Convenient determination of exposures and risk for various types of radionuclides.	Not applicable for cases of near-field dispersion around buildings.
SCREEN3	Base model uses standard Gaussian dispersion models with some accounting for the effects of the emitting building. A second algorithm calculates concentrations in the immediate downwind wake of the emitting building, but not on the roof. Another more general model not discussed here is the ISCPRIME model, which is still not recommended for rooftop receptors.	Easy to use for single stack. Has some accounting for building effects.	Not applicable for intakes on same building roof as exhaust stack. Needs experience for some cases with elevated intake above the stack. Only predicts concentrations. Still needs added calculations for exposure and risk.
ASHRAE	Dispersion equations developed from wind tunnel tests of stacks on roof of single building.	Best numerical model for intakes on same roof as stack. Can be adapted for other building situations with experience. The most accurate model for dispersion around buildings except for direct wind tunnel testing.	Only predicts concentrations. Still needs added calculations for exposure and risk. Needs experience to apply in complicated building geometries.
WIND TUNNEL	Scaled modeling of airflow around buildings. Uses tracer gases to follow dispersion of exhausts.	Most accurate model for dispersion around buildings.	Only predicts concentrations. Still needs added calculations for exposure and risk. More expensive than numerical models.
COMPUTATIONAL FLUID DYNAMICS (CFD) **(Not Recommended)**	Detailed computer modeling of wind flow surrounding the building and nearby buildings.	Provides good flow visualization graphics.	Not as accurate as wind tunnel modeling for flow around buildings if using standard k-epsilon models. More expensive than other numerical models. Only predicts concentrations. Still needs added calculations for exposure and risk.

Another problem with some mathematical models is their limited applicability with respect to specific building, exhaust and receptor configurations. Models such as SCREEN3 and CAP88, which were developed from Gaussian-type plume dispersion equations, should be used only to predict impacts from tall isolated stacks or to predict impacts at locations significantly downwind of the stack (e.g., at the property line). SCREEN3 does have an algorithm to account for building influence, but the calculated results are only applicable to the nearby ground and building sides, not on rooftop locations. Impacts at receptors located near the stack are best predicted using dispersion equations published in the ASHRAE Handbook. Because these equations have themselves been derived from wind tunnel data, they typically result in more realistic estimates of impacts.

In cases where dilution levels are predicted to be insufficient, improvements can be achieved with design modifications such as stack height increases, increases in discharge velocities and strategic stack placement along the building roof, and with respect to other sources.

DOSAGE CALCULATIONS

Dispersion model results must be combined with dosage information to determine annual dosage levels. CAP88 and COMPLY conveniently calculate dosage levels automatically. However, the dispersion portion of these models is either not applicable to most building situations (CAP88) or very strict (COMPLY).

The RWDI recommended approach is to use the same dosage calculation procedure used in COMPLY following the screening methods of the NCRP Publication 123I (1996), combined with the ASHRAE dispersion model. In effect, RWDI replaces the very strict dispersion portion of the COMPLY model with the ASHRAE dispersion modeling. To date, the ASHRAE methodology has been accepted by state regulatory agencies.

SUMMARY AND SUGGESTIONS

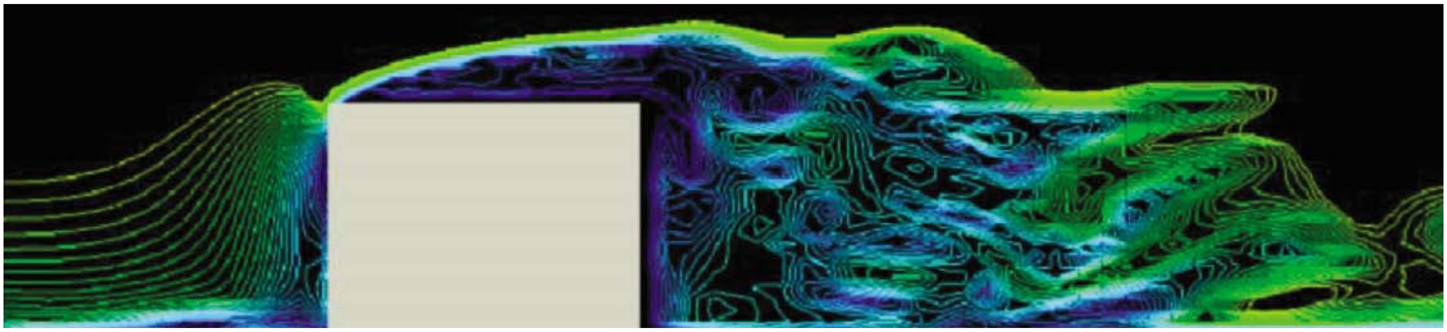
To meet applicable MPC and ADL regulations, radionuclide exhaust systems must be designed to meet both maximum permissible concentration limits at the stack and to meet allowable dosage limits both on and off-site. MPC limits are best met with emission controls, such as particulate filtering and delay lines. Close coordination with the radiation safety officer and the design team is recommended to determine the regulatory limits and emission scenarios applicable to the particular facility.

Strategies for meeting ADL limits in the surrounding area include adequate stack height and stack placement with respect to building intakes and avoiding building intakes that are situated above the stack or too close to the stack. Using a dispersion model such as ASHRAE yields more accurate modeling results than the stricter models within COMPLY. This allows a smaller stack height than would otherwise be required. The drawback to using the ASHRAE model is that some experience is needed in applying the results to complicated building geometries.

REFERENCE

(1) World Nuclear Society, "Radioisotopes In Medicine", www.world-nuclear.org, May 2004.

(2) NRC (1997). U.S. Nuclear Regulatory Commission. Code of Federal Regulations, 10 CFR Part 20.1101, Section 20.1101(d).



Model shows that winds flowing over and around a building create complex flow patterns

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