The gaseous discharges at ISIS and the activated air composition effect

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Abstract. Activated air at ISIS is discharged through five ventilation stacks. In each stack, a portion of activated air is diverted through a drum where the beta and gamma activity is measured using two Geiger–Muller detectors (one of them is surrounded by a beta particles shield). The procedure to get conservative estimate of the activity discharge rate from the stack(s) is presented in this paper. It is shown that without any knowledge about the relative proportions of radionuclides, gas mixing and details of ventilation system it is possible to have most conservative estimate (maximal value) of the specific activity of the activated air. This most conservative estimate of activity discharge rate is what is usually needed to check the status of compliance with applicable regulations.

1. Introduction
Activated air at ISIS Neutron and Muon Source is discharged through the ventilation stacks. Each stack has a simple, but effective, monitoring system that takes filtered air from downstream of the stack, feeds it into a drum (200 litre volume) and returns the air from the drum to the stack [1]. The $\beta\gamma$ activity of the air is measured using two Geiger–Muller (GM) detectors located in the middle of the drum [1, 2, 3, 4]. Air from the discharge stack is continuously passed through the drum so, one can say, the air in the drum has the same specific activity as the air being discharged up the stack. By measuring the count rate of the detectors and with knowledge of the gas flow rate up main stack, gas flow rate through a drum, detection efficiency and, what is most important, the relative proportions of radionuclides in activated air, the value of air specific activity can be obtained. In reference [4], equations for the rate of discharge of $\beta\gamma$ activity from a stack were given. In the complete mixing approximation (assuming that gas entering the drum is immediately distributed uniformly throughout the volume of the drum), the activity discharge rate (given in Bq/s, for example) is:

$$A'_{com-mix} = \frac{FC'}{f\epsilon} \sum_{i=1}^{N} \frac{\lambda_i r_i}{1+\frac{r_i}{\lambda_i T}}$$

(1)
Here, $F$ is the gas flow rate up main stack, $C'$ is the total count rate from the Geiger–Muller detector$^1$ and $f$ is the gas flow rate through a drum ($f << F$). $\lambda_i$ is the decay constant$^2$ for the radionuclide $i$ and $r_i = n_i/n_{\text{total}}$ is the relative proportion of the radionuclide $i$ in the activated gas ($n_i$ and $n_{\text{total}}$ are given in number of atoms per unit volume). The detection efficiency $\epsilon$ is assumed to be equal for all $i$ ($\epsilon_i = \epsilon$). $T$ is the transit time through the drum ($T = V/f$, where $V$ is the volume of drum).

In the no-mixing approximation (assuming that every molecule of gas entering the drum takes the same, transit, time to pass through the drum), the activity discharge rate is:

$$A'_{\text{no-mix}} = \frac{FC'}{f \epsilon T} \sum_{i=1}^{N} \lambda_i r_i \left(1 - e^{-\lambda_i T}\right).$$  \hspace{1cm} (2)

Both equations have identical form when the half-lives of all radionuclides are much longer (or much shorter) than transit time through the drum:

$$A' = A'_{\text{com-mix}} = A'_{\text{no-mix}} = \frac{FC'}{f \epsilon T} \sum_{i=1}^{N} \lambda_i r_i.$$

The 'beauty' of equation (3) lies in the fact that all the variables can be directly measured so it can be used as a first estimate of $\beta\gamma$ activity discharges from the stacks.

2. Analysis

The main condition for using equation (3) for stack discharge calculations is that the half-lives of all radionuclides in activated air are significantly different than transit time $T$ through the drum. The most frequently seen ($\beta\gamma$ emitting) radionuclides in activated air at proton accelerators are$^3$: $^{11}$C ($T_{1/2}=20.4$ minutes), $^{13}$N ($T_{1/2}=9.96$ minutes), $^{15}$O ($T_{1/2}=2.04$ minutes) and $^{41}$Ar ($T_{1/2}=109.6$ minutes). The measurement of transit time $T$ through the one of the ISIS drums using a $^{85}$Kr source gave the following value: $T = 6$ minutes$^5$. As can be seen, the half-lives of the radionuclides listed above are similar to the transit time. The consequence is that equation (3) underestimates stack(s) discharges.

This means that equations (1) or (2) must be used to obtain the 'correct' value of the activity discharge rate, or in other words, the relative proportions of radionuclides in air (at measuring/discharging point) must be known. Generally speaking, the relative proportions of radionuclides can be estimated via Monte Carlo simulations of production of airborne radionuclides. However, in some cases there are many different production spots of airborne radionuclides and/or complicated ventilation systems so performing such a simulation is not an easy task. ISIS Neutron and Muon Source with its accelerator, two target stations and very complicated ventilation system is a typical illustration of such a case. This means that in the ISIS case the relative proportions of radionuclides at the discharging point can be significantly different than corresponding values at the production spots. So the interesting question here is: Is it possible to have any sort of estimate of the air specific activity if the relative proportions of radionuclides in activated air are practically unknown?

Figure 1 shows how strongly the activity discharge rate depends on the relative proportions of four radionuclides listed above. The procedure for making this plot was to: vary $r_i$ values

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1. As the radionuclides of interest all emit $\beta^-$ or $\beta^+$ particles with 100% branching ratio on each decay, it is assumed that the total activity discharged will be proportional to the difference in counts of the unshielded and shielded GM detectors.

2. $\lambda = (\ln 2)/T_{1/2}$, where $T_{1/2}$ is a half-life.

3. Beta emissions from $^4$He are below the minimum energy which can be detected by the GM detectors, and it is monitored using a bubbling system. $^7$Be is particulate and it is trapped by the HEPA filters.
between 0 and 1 (taking into account that: $\sum_{i=1}^{4} r_i = 1$), use equations (1), (2) and (3) to calculate the following ratios:

$$M_{\text{com-mix}} = \frac{A'_{\text{com-mix}}}{A'},$$

and

$$M_{\text{no-mix}} = \frac{A'_{\text{no-mix}}}{A'},$$

and plot these ratios against all the possible combinations of the relative proportions of four radionuclides. Visual inspection of Figure 1 reveals that, in the worst-case scenario, 'real' activity discharge rate can be more than 3 times higher than the value calculated using equation (3). As expected, the correction factors for complete-mixing case are always higher than corresponding values in no-mixing case.

![Figure 1. The multiplicative factor $M$ (see text for definition) versus all the possible combinations of the relative proportions of four characteristic radionuclides ($^{11}$C, $^{13}$N, $^{15}$O and $^{41}$Ar) in activated air. The step in varying the relative proportions was 0.05 so there is 1725 combinations in total.](image)

It has to be noted, however, that worst-case scenario presented above is not realistic. Very high values of $M_{\text{com-mix}}$ and $M_{\text{no-mix}}$ correspond to very big proportion of $^{15}$O in activated air and this is highly unlikely. Available literature data shows that maximal expected fraction of $^{15}$O in activated air at proton accelerators is not higher than 20%. The multiplicative factor values in this case are shown in Figure 2.

On the basis of the above mentioned, one could say that even without any knowledge about the relative proportions of radionuclides, gas mixing and details of ventilation system it is possible to have conservative estimate on the activity discharge rate from ventilation stack(s). The procedure to get this, most conservative, estimate (if a monitoring system described in this paper has been used) is to:

- measure count rate from the Geiger–Muller detector(s), detection efficiency, gas flow rate up main stack and gas flow rate through a drum;
- calibrate the drum (measure the transit time);
- use the equation (3) to calculate first estimate of the activity discharge rate;
- calculate factors $M$ using the procedure described above;
and multiply obtained result for the activity discharge rate by the maximal value of $M$ (in this example $M = 2.7$ for transit time of 6 minutes).

![Figure 2](image_url)

**Figure 2.** The multiplicative factor $M$ (see text for definition) versus possible combinations of the relative proportions of four characteristic radionuclides ($^{11}$C, $^{13}$N, $^{15}$O and $^{41}$Ar) in activated air. The relative proportion of $^{15}$O is varied in the range [0.0, 0.2].

### 3. Conclusions

In this paper, the procedure to get conservative estimate of the air activity discharge rate from the ventilation stacks is presented. It is shown that without any knowledge about the relative proportions of radionuclides, gas mixing and details of ventilation system it is possible to have most conservative estimate (maximal value) of the specific activity of the activated air. This most conservative estimate of activity discharge rate is what is usually needed to check the status of compliance with applicable regulations.

### References

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