This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-96SR18500 with the U. S. Department of Energy.

USE OF DAC-HOURS FOR RADIATION WORK PERMIT SUSPENSION GUIDES AND VALIDATION OF RESPIRATORY EQUIPMENT SELECTION AT THE SAVANNAH RIVER SITE

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ABSTRACT

Historically, the Savannah River Site, like many Department of Energy sites, has used some multiple of the expected Derived Air Concentration (DAC) of a radionuclide as a suspension guide for Radiological Work Permits (RWP) or validation of selected respiratory protection equipment. The term DAC expresses the concentration of a radionuclide in air, typically in μCi/cc. Even though the term DAC is derived from an intake of radioactivity (Annual Limit on Intake) that would result in defined estimated dose to a worker, knowing only the DAC value does not allow a worker's potential dose to be determined. Recently, the Savannah Rive Site has converted to the use of DAC-hours for RWP suspension guides and respiratory equipment validation. The term DAC-hr takes into account not only the concentration of the radionuclide in air (DAC) but also the time the individual was exposed allowing an estimate of a worker's dose to be determined. The conversion to DAC-hrs resulted in four benefits to the radiation protection program without increasing the risk to workers; (1) consistency with the constant air monitor (CAM) alarm setpoint protocol; (2) consistency with Internal Dosimetry terminology; (3) an a priori determination of the potential risk to a worker; and (4) reduced complexity/error in field calculations. This paper outlines the justification for the conversion to DAC-hrs, the protocols used for field and count room calculations, and the implementation process utilized at the Savannah River Site

BACKGROUND

It is important to first define what DAC and DAC-hr are in order to highlight the similarities and differences between the two. The two are defined as follows [DOE 1999]:

DAC For the radionuclides listed in Appendix A of 10 CFR 835, the airborne concentration that equals the ALI divided by the volume of air breathed by an average worker for a working year of 2000 hours (assuming a breathing volume of 2400 m^3). The values are based upon the derived airborne concentration found in Table 1 of the U. S. Environmental Protection Agency's Federal Guidance Report

No. 11, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestio*n, published September 1988. DAC is expressed in terms of concentration (μCi/cc).

Note: ALI is the acronym for Annual Limit on Intake

DAC-hr The product of the concentration of radioactive material in air (expressed as a fraction or multiple of the DAC for each radionuclide) and the time of exposure to that radionuclide, in hours. DAC-hr is expressed in terms of activity (μCi).

As the definitions show, the term DAC only expresses the concentration of a radionuclide in air, typically in μCi/cc. Even though the term DAC is derived from an intake of radioactivity (ALI) that would result in defined estimated dose to a person, knowing only the DAC value does not allow a person's potential dose to be determined. The term DAC-hr, however, takes into account not only the concentration of the radionuclide in air (DAC) but also the time the individual was exposed allowing an estimate of a person's dose to be determined.

The ability to normalize a worker's exposure to airborne radionuclides to DAC-hrs, and hence a potential dose, is the advantage of using DAC-hrs over DAC for an RWP suspension guide and the validation of respiratory protection equipment.

DAC-hrs have been, and continue to be, used for many years by SRS for determining CAM alarm setpoints per DOE guidance [DOE 1994] and deciding whether a worker exposed to airborne radioactivity needs to be assigned to a special bioassay program. As such, the use of the term DAC-hr is not foreign to workers at SRS.

DISCUSSION

This discussion section is broken down into five sub-sections:

1. How DAC-hrs relates to a person's potential dose, in CEDE,
2. The use of DAC-hrs for an RWP Suspension Guide,
3. The use of DAC-hrs for validation of respiratory protection equipment,
4. Protocol for calculating DAC-hrs,
5. Implementation process used at SRS.

<u>DAC-hrs and Dose (CEDE)</u>

As stated in the definition of DAC, the concentration value for a radionuclide is based on the ALI (normally in μCi), and assumed worker exposure period of 2000 hrs/yr and an assumed breathing rate of 2400 m^3/yr (1.2 m^3/hr for 2000 hrs). An ALI is defined as follows [DOE 1999]:

The derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man (ICRP Publication 23) that would result in a committed effective dose equivalent of 5 rem or a committed dose equivalent of 50 rem to any individual organ or tissue.

When discussing DAC, the ALI of interest is the inhalation ALI. There are two inhalation ALIs for each isotope based on stochastic effects (SALI) and non-stochastic effects (NALI). The dose limit is 5 rem CEDE for the SALI and 50 rem CDE for the NALI. As both the 5 rem CEDE and 50 rem CDE are the annual limits within 10 CFR 835 [DOE 2001], the DAC value is determined using the lesser of the SALI and NALI. For example, the ALI listed in Federal Guidance Report 11 for class W Pu-238 is 0.007 μCi. The corresponding DAC value is calculated per equation 1.

$$\frac{0.007\,\mu Ci/yr}{\left(1.2\,m^3/hr\right)\left(2000\,hr/yr\right)\left(1E+06\,cc/m^3\right)} = 2.92E-12\,\mu Ci/cc \qquad \{Eq. 1\}$$

With the result rounded to the familiar 3.0E-12 μCi/cc given in 10 CFR 835. Once the DAC is calculated, it is transparent to the user whether the DAC is based on the NALI or the SALI.

It is normal health physics convention to use the SALI limit of 5 rem/yr when determining an estimated dose to a worker from a DAC-hr exposure if this determination is only to be used as an estimate and not a final dose calculation. As such, each DAC-hr of exposure is assumed to result in 2.5 mrem CEDE $\left((5000\,mrem/2000\,DAC-hr) = 2.5\,mrem/DAC-hr\right)$ to an unprotected worker.

The terms DAC and DAC-hr can be easily related to the terms dose rate and dose. The term DAC relates a dose rate where if the airborne radioactivity is at a one DAC level, the dose rate in the area is 2.5 mrem/hr. The term DAC-hr is a dose, if an unprotected worker is exposed to 1 DAC-hr their estimated dose is 2.5 mrem.

DAC-hrs as an RWP Suspension Guide

The previous RWP airborne radioactivity suspension guides at SRS were based on the DAC values determined from an air sample. As previously discussed, a DAC value does not provide the information needed to determine whether a person was potentially exposed to an extent that requires a special bioassay.

As an example, if you are told that worker A was exposed to an airborne concentration of 100 DAC without the use of respiratory equipment, the only conclusions you can come to is that the worker was in a area that should have been posted as an airborne radioactivity area and the estimated internal dose rate in the area is 250 mrem/hr. On the other hand, if you were told that worker A was exposed to 100 DAC-hrs of airborne radioactivity without respiratory equipment, you can quickly estimate a CEDE exposure of 250 mrem and determine the necessary special bioassay.

The advantage of DAC-hrs can also be realized in the ability to measure the exposure using Field calculations. When using DAC, the amount of radioactivity deposited on a typical retrospective air sample is insufficient to easily discern from background counts for alpha emitting radionuclides. SRS used the Field DAC calculation (simplified formula) contained within equation 2 to estimate the DAC of the job-specific air sample.

$$(Y)\left(\frac{dpm}{ft^3}\right) = DAC \qquad \text{\{Eq. 2\}}$$

Where: DAC = Air sample concentration

dpm = net disintegrations per minute (d/m)

ft^3 = volume of sampled air during time period of interest

Y = a rounded conversion factor derived from equation 2.1 (10 for Pu-239)

$$Y = \left(\frac{4.5\text{E}-07}{(28{,}320)(\text{SA})(\text{CE})(\text{DAC}_\text{i})}\right) \qquad \text{\{Eq. 2.1\}}$$

Where: 4.5E-07 = dpm to μCi conversion

28,320 = ft^3 to cc conversion

SA = self-absorption factor of the sampling medium

CD = collection efficiency of the sampling medium

DAC_i = DAC value of the radioisotope of interest

The use of this equation requires the Radiological Controls Inspector (RCI) to calculate the dpm required for a specific DAC suspension guide as the sample volume changes. Table 1 gives the dpm values corresponding to a 50 DAC Pu-239 suspension guide using an air sampler with a 4 ft^3/min flowrate.

As can be seen from Table 1, the dpm for 50 DAC Pu-239 corresponds, over a two hour task period, to a range of 300 to 2400 dpm (DAC dpm column).

Table 1 – dpm versus volume: DAC & DAC-hrs

Time (min)	Volume (ft^3)	DAC dpm	DAC-hrs dpm
15	60	300	1210
30	120	600	1210
45	180	900	1210

Table 1 – dpm versus volume: DAC & DAC-hrs (Cont.)

60	240	1200*	1210*
75	300	1500	1210
90	360	1800	1210
105	420	2100	1210
120	480	2400	1210

*These two values should be the same; the small difference is due to rounding of the Y value used in equation 2.

Equation 3, using the same assumption in equation 2 that the exposure time equals the sample time, calculates the dpm, as read on a portable survey instrument, of an air sample filter paper corresponding to a specific DAC-hr limit.

$$dpm = \left(DAC_i\right)\left(\dot{V}\right)\left(2.832E4\, {}^{cc}\!/_{ft^3}\right)\left(60\, {}^{min}\!/_{hr}\right)\left(2.22E6\, {}^{dpm}\!/_{\mu Ci}\right)(0.8)\left(DAC - hr\right) \quad \{\text{Eq. 3}\}$$

Where: DAC_i = DAC value for the isotope of interest

$\dot{V}$ = Sample flow-rate

DAC-hr = DAC-hr limit

Using equation 3 for a 50 DAC-hr Pu-239 suspension guide with a 4 ft^3/min sample flowrate, the resulting filter paper α activity is about 1210 dpm. This dpm value remains constant over the entire period of the task as shown in Table 1 (DAC-hrs dpm column). Since this value remains constant over the duration of the task, the RCI will not have to calculate the Field DAC dpm values during the task. The DAC-hr values can be pre-calculated in a basis document using expected flow-rate(s) and then used directly when covering the task. This would eliminate the need to document interim calculations on a radiation survey logsheet or some other document.

In addition, the DAC-hr dpm values are not time dependant. Since the Field DAC calculation is based on volume, the technician is forced to either read the filter paper on a pre-determined time interval (SRS used 15 minutes) or re-calculate for every reading based on the volume acquired. The DAC-hr value is dependant on flow rate, not volume. Flow rate for the time periods involved for job coverage can be assumed a constant, thus the dpm value is constant whether the reading is taken two minutes into the task or two hours.

It is interesting to note from Table 1 and the DAC-hr result from equation 3 that the 60 minute DAC value and the DAC-hr value are essentially the same. This is expected as 50 DAC over 1 hour would be 50 DAC-hrs. However, Table 2 shows that the 120 minute DAC dpm is twice that of the DAC-hr calculation and the potential DAC-hrs to a worker is actually 100 DAC-hrs at this point. This illustrates another drawback of using DAC values for suspension guides. Although it can be considered 'conservative' when looking at exposure times of less than 1 hour, it is non-conservative when the exposure period is greater than 1 hour.

Table 2 – Equivalent DAC-hr for 50 DAC limit

Time (min)	Volume (ft^3)	DAC dpm	DAC	DAC-hrs
15	60	300	50	12.5
30	120	600	50	25.0
45	180	900	50	37.5
60	240	1200	50	50.0
75	300	1500	50	62.5
90	360	1800	50	75.0
105	420	2100	50	87.5
120	480	2400	50	100.0

To put this in perspective, assume the task involved a short term release of Pu-239, such as might occur during an initial line break, followed by no further release of radioactivity. If the short term release deposited 350 dpm alpha over the first 15 minutes, the task would be stopped due to exceeding the RWP suspension guide of 50 DAC (300 dpm). However, in terms of DAC-hrs 350 dpm only corresponds to ≈15 DAC-hrs or 38 mrem. Conversely, if the task consisted of several small or ongoing releases, such as with welding or grinding, to where the air activity was just under the suspension guide until 2 hours into the task when the reading was 2450 dpm, only then would the task be stopped but the corresponding DAC-hr exposure would be 101 DAC-hrs or about 250 mrem. Only through the use of DAC-hrs can an RWP suspension guide represent a consistent risk to the worker over the entire time of the task.

DAC-hrs for Validating Respiratory Protection Equipment Selection

Respirators are typically selected based on one or more of the following three criteria:

1. Tribal knowledge says it's the smart thing to do based on history of related tasks (e.g., line breaks, heating, grinding, specific process evolution such as drawing samples, etc.);
2. Direct airborne radioactivity measurements; and
3. Contamination levels of equipment, room, etc.

For practical purposes, respirators are normally selected based on tribal knowledge and contamination levels. Direct airborne measurement is not normally available for a task although historical information can be used in the selection process. Once the respiratory equipment has been selected, it should be validated through air sampling that the equipment was adequate for the task performed.

The previous SRS procedure for selecting respiratory protection stated that "Respirators are selected so that the concentration inhaled by the wearer will not exceed 1 DAC airborne radioactivity." In the same vein as the RWP suspension guides, only the DAC value was used to validate that the respirator selected was adequate. The same pitfalls of using DAC for RWP suspension guides also exist for respiratory selection/validation; the main one being that use of DAC does not convey sufficient information to determine a potential exposure to a worker.

One of the philosophies used in the selection and validation of respiratory protection equipment is that one must select respiratory equipment such that the DAC, when divided by the protection factor (PF), cannot exceed unity. This philosophy was specifically addressed in Radiological Control Technical Position (RCTP) 2000-05 [DOE 2000]. This RCTP suggests that for an initial approach, consider selecting a respiratory protection device which has an assigned protection factor greater than the expected concentration values, in terms of DAC. However, it is recognized that there are situations where, for ALARA considerations, the total exposure may be lower using a respiratory protection device with a lower assigned protection factor such as in areas with high external dose rates. Nonradiological hazards (e.g., heat stress, reduced visibility) may also influence selection of respiratory protection devices. The RCTP goes on to further state:

> *As an alternate approach, to ensure the radiological protection exposure limit of 5 rem TEDE in a year is not exceeded, one may use the conversion of 2.5 millirem per DAC-hour and account for the protection factor of the respiratory protection device and the time in the area.*

It was recommended, and accepted, to change the selection/validation criteria within SRS procedures from one DAC to four DAC-hrs (potential of 10 mrem CEDE) based on the information contained within the RCTP and the desire not to trigger a special bioassay during routine wearing of respiratory equipment. This change will provide flexibility in the selection and validation process with no appreciable increased risk to the worker.

For example, when looking at a short term (10 minute) task using a negative pressure respirator (PF of 50) and a 4 DAC-hr criteria, the average DAC value that can be present in the air is determined by equation 4.

$$\frac{(4\ DAC-hr)(PF\ of\ 50)}{(10min)\left(hr/60min\right)} = 1200\ DAC \qquad \{Eq.\ 4\}$$

Looking at longer-term tasks provides (as with the previous RWP suspension guide discussion) some insight into the possible non-conservativeness of using DAC for selecting a respirator. Assuming a task of duration of 8 hours while using a negative pressure respirator (PF of 50) at 45 DAC (acceptable with previous procedures), the estimated dose to a worker is calculated using equation 5.

$$\frac{(45\ DAC)(8\ hours)}{(PF\ of\ 50)} = 7.2\ DAC-hrs \qquad \{Eq.\ 5\}$$

This DAC-hr exposure is within 0.8 DAC-hrs of requiring a special bioassay based on an SRS action level of 8 DAC-hr. Limiting respirator validation to 4 DAC-hrs for the task duration would have required that a higher PF respirator be selected for this task. In addition, the use of a 4 DAC-hr criteria would ensure that a worker's estimated exposure would be at least a factor of 2 below the special bioassay action level of 8 DAC-hrs.

Protocol for calculating DAC-hrs

Previous SRS guidance contained a DAC-hr equation to determine the potential exposure to an individual from elevated airborne radioactivity. This calculation was used for incidents where Internal Dosimetry would become involved. The formula from this previous guidance for a retrospective air sampler is reproduced as equation 6.

$$\frac{(dpm)}{(9.0E12)(DAC_i)(PF)} = DAC - hour \qquad \text{\{Eq. 6\}}$$

Where: PF = Protection Factor of respiratory protection

9.0E12 = Conversion Factor

The conversion factor 9.0E+12 takes into account the filter collection efficiency, filter self-absorption, an assumed sample flow rate of 3 ft^3/min, and required unit conversion factors. Equation 6 assumes that the exposure time of the individual is equal to sampling time of the air sample. The assumptions in equation 6 should yield a conservative estimation of exposure since the sample flow rate is normally >3 ft^3/min and the exposure time of the individual cannot be greater than the sampling time of the air sample and may be less.

Expanding equation 6 to remove the inherent conservatism results in equation 7.

$$\frac{(dpm)\left(4.5E-07\, {}^{dpm}\!/_{\mu Ci}\right)(T_E(hrs))}{\left(\dot{V}\, {}^{ft^3}\!/_{min}\right)\left(2.832E+4\, {}^{cc}\!/_{ft^3}\right)\left(60\, {}^{min}\!/_{hr}\right)(T_S(hrs))(DAC_i)(PF)} = DAC - hours \qquad \text{\{Eq. 7\}}$$

Where: T_E = Time of exposure (hours)

T_S = Sample time (hours)

Combining the constants in equation 7 results in equation 8.

$$\frac{(dpm)(2.65E-13)(T_E(hrs))}{\left(\dot{V}\, {}^{ft^3}\!/_{min}\right)(T_S(hrs))(DAC_i)(PF)} = DAC - hours \qquad \text{\{Eq. 8\}}$$

By assuming that the exposure time equals the sampling time when performing field counting for job coverage and specifying 'most restrictive' DAC values, a simplified formula can be derived using a 'Z' factor, much like what was performed for deriving equation 2, and results in equation 9.

$$DAC - hr = \frac{dpm}{Z} \qquad \text{\{Eq. 9\}}$$

Where the Z values are taken from Table 3.

Table 3 – Z-values for estimating DAC-hrs from Field Counts

Flow (ft^3/min)	Pu-239	Pu-238	Uranium	Sr-90
3	20	30	200	20,000
4	25	40	250	25,000
5	30	50	300	30,000

Implementation process used at SRS

The first step in the process was to gain senior management support for this effort. In the presentation to senior management, an implementation process was laid out that included the following:

- Put together a team of Radiological Controls Organization (RCO) personnel.
- Train team on the concept of using DAC-hrs.
- Have the team identify the required procedure and/or policy changes.
- Create official training package for RCO personnel through the SRS Training Department.
- Train RCO personnel in one facility in order to run a pilot program.
- Run a pilot program.
- After evaluating the pilot, revise the training and procedures as needed and continue training all RCO personnel for full site implementation.

It was estimated that it would take about 14 weeks from the time of management approval to when a pilot program could be implemented.

Fortunately, SRS had an existing team made up of both operational and technical radiation protection personnel. This team, the Air Monitoring Integration Team (AMIT), had a history of developing and implementing improvements to the Site's air monitoring program. The AMIT developed the implementation plan and presented it to senior management. Once managements buy-in was obtained, the AMIT sponsored a DAC-hr implementation team consisting of mainly operational Radiological Controls personnel (technicians, first-line managers, and Facility Managers) along with a Health Physicist. The team was headed by a senior Radiological Controls manager. The first meeting of the DAC-hr team was a training session to bring everyone up to speed on what was to be accomplished and the technical aspects/justification for the change. Once everyone understood what was to be accomplished, the team reviewed the current SRS procedures, policies, and guidance documents used in the day to day activities associated with a radiological protection program to identify revisions that would be needed to change from DAC to DAC-hrs.

After the revision changes were identified, 'mirror' procedures were developed. These procedures contained the same requirements/wording as its sister procedure except that it had the direction necessary to implement DAC-hrs. The SRS procedures group maintained both sets of procedures and ensured that changes other than those associated with DAC-hrs were made in both procedures.

Once the procedures were in place, training was performed for the pilot facility. This training covered the following:

- Reason for change,
- Technical justification,
- Overview of procedure revisions,
- Baseline knowledge of uptake, intake, DAC, and DAC-hr,
- Practical example using a fictional task from pre-planning to completion,
- Practical examples of the calculations needed to be performed by both Field and Count Room personnel.

With the procedures approved and training complete, the pilot program was begun in a single facility. A review of the pilot was performed about 4 weeks after implementation to determine if any improvements could be made for implementation in the next facility. After this review was complete and identified improvements implemented, a phased approach was used for site implementation.

The phased approach allowed other facilities to join the pilot program once training of their personnel was complete. The training was accomplished through both the routine cycle training given to Radiological Controls personnel and special training sessions targeted for a single facility. In addition, other information sessions were arranged between facility Radiological Controls management and the DAC-hr subject matter expert to facilitate a smooth transition.

To ensure full implementation across all site facilities, a final implementation date was agreed upon by senior management. This mandated that those facilities not deciding to become a part of the pilot program would still have to transition by that date. Full transition by the site occurred in June of 2003.

CONCLUSION

The use of DAC-hr in place of DAC at SRS facilities has been a success. The vast majority of comments from Radiological Controls personnel have been positive with the main comment being how much easier it is to implement.

The change from DAC to DAC-hr from the time the technical basis document was authored until it was implemented on a sitewide basis was almost two years. The time until the pilot program was implemented was about nine months. Considering that SRS has over 400 Radiological

Controls personnel assigned to about twenty specific facilities, the time frame to implement was not excessive. The majority of site facilities transitioned to DAC-hr prior to the mandated site implementation date.

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