4.0 ACTIVATION OF METAL ISOTOPES in Motor-Operated Valves

The face material on motor operated valves is composed of wear resistant metal alloy, designated as Stellite. This is a proprietary alloy, patented by the Deloro Stellite Company. The principal constituent of the alloy is cobalt. Other constituents are nickel, iron, aluminum, boron, carbon, chromium, manganese, molybdenum, phosphorus, sulphur, silicon, and titanium, in various proportions. Usually at least four of these other metals are part of a particular Stellite alloy. The applications are many, but the primary characteristic specified for these alloys is wear resistance.

As the Nuclear Regulatory Commission focused more attention on the ALARA (As Low As Reasonably Achievable) concept, power plant operators began to focus attention on the principal causes for the doses that workers were receiving during plant shutdown maintenance activities, as well as activities during normal operation. The Cobalt-60 isotope was determined to be one of the major (if not the major) contributor to these doses. The source of cobalt is primarily wear resistant alloys, with motor operated valve faces being the major source of the cobalt “contamination.”

Though the alloys on the face (of the gates in the case of gate valves) are wear resistant, each operation of the valve involves some wear, and release of very small grains of the metal. One would expect that milligram quantities of cobalt thus released would have little effect on the reactor primary system. The following sections will show how very small quantities of material can represent high amounts of radioactivity in certain isotopes, particularly Cobalt-60. The flecks of material would eventually be removed by filters in the primary system coolant loop. However, these flecks usually become attached or lodged in parts of the primary system, particularly in fuel assemblies in the high neutron flux of the core.

Cobalt activation is an issue in design of the newer plants. The concerns are not merely for operational personnel radiation exposure, but also for issues involved in eventual decommissioning and decontamination.

4.1 RADIOACTIVE ACTIVATION

Cobalt exists in nature with only one isotope, cobalt-59. This isotope has a thermal neutron absorption cross section of 37 barns. The resulting isotope, Co-60, has a half-life of 5.27 years, and emits two gamma rays with essentially all of its decay, a 1.17 Mev and a 1.33 MeV gamma ray, for a total gamma energy release of 2.5 MeV per decay.

Writing a differential equation for activation of an isotope in a neutron flux, we represent the rate of change of the number (N) of the isotope being produced:

dN/dt = production - decay

Production = Q

= $[(N\text{-}Avag.)/(atomic\ weight)] \times (mass)(\sigma) \times \varphi$

Where

$N\text{-}Avag.$ = Avagadro's # = 0.6022E24

mass (m) is in grams

The atomic weight is that of the parent isotope, cobalt 59.

σ = the cross section for absorption, in units of E^{-24} square centimeters (Note the E^{24} and E^{-24} will cancel out.)

φ = the applicable neutron flux.

For thermal neutron activation, which is the predominate activation for Co-60, the cross section is 37 barns, and thermal flux in the core of a commercial light water reactor is in the range of 1E12 to 1E13.

The decay rate is represented by a product of the decay constant and the number of atoms of Co-60 present at any given time.

Decay rate = $\lambda N = [(\ln 2) / (half\ life)] \times N$

The final differential equation for the isotope Co-60, number of atoms N, is

$$dN/dt + \lambda N = Q = [(N\text{-}Avag)/59](m)\sigma\varphi$$

The solution, for steady exposure in a neutron flux for a time period t_{exp} is

$$N(Co\text{-}60) = [Q/\lambda] \times \{1 - \exp(-\lambda t_{exp})\}]$$

Equation (4.1)

The activity of the cobalt-60 is the number of the atoms, N, times the decay constant. Hence, the activity, in disintegrations/second is given by:

$$A\ (dis/sec) = Q[1 - \exp(-\lambda t_{exp})]$$

Equation (4.2)

Following removal from the flux, the Co-60 isotope will decay by the factor $\exp(-\lambda t_{dec})$. Note, in all of the above equations, the units involved in λ and the time, t, must be the same, i.e. if the half life is in seconds, the time must be in seconds. If the half life is in years, the time of exposure or decay must be in years.

EXAMPLE: Consider one milligram of Co-59 sloughing off of the face of a MOV, and lodging in the core and being. exposed to a thermal flux of 1E13 for two years. At the end of the two years the particle is released and attaches itself to a part of the piping outside of the core.

Activity = A = (0.602/59) x 0.001 x 37 x1E13 x [1- exp(-0.693x2 / 5.27)]
= 3.78E9 [1 - exp(-0.263)]
= 873E6 disintegrations per second

The Curie is the more common unit of activity,
1 Curie = 3.7E10 disintegrations per second
giving the result of 0.024 Curies.

4.2 PERSONNEL DOSE - A "RULE OF THUMB"

The radiation dose to persons exposed to gamma rays emanating from materials involved in nuclear reactor operation can be approximately represented by a simple "Rule of Thumb" because most gamma rays involved around reactors have the same damaging effectiveness as a function of energy. The "Rule of Thumb" is:

$$\text{Dose Rate (Rad/hour)} = 6\text{x(Curies)x(Energy in MeV)/(distance)}^2$$

Equation (4.3)

where the distance is in feet.

For the example just discussed, of one milligram of cobalt after being exposed in a reactor for two years, the dose at a distance of three feet is

6 x 0.024 x 2.5 / 32 = 0.040 R/hour
= 40 mR/hour

Note, this is the dose from just one milligram of cobalt (Co-59, the natural isotope). The actual mass of the Co-60 in that one mg particle is 347 nanograms!