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Modelling Emissions of Carbon-14 and Argon-41 Released from a CANDU 6 Reactor

by

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Radioactive emissions from CANDU 6 reactors around the world are small, historically well below regulatory limits for radiological protection of the public. Nevertheless, there is an on-going program within AECL to improve the design and operation of nuclear power plants. Modelling the behaviour of key radionuclides released from a CANDU 6 reactor can play a key role in making such improvements.

Carbon-14 and the noble gases are two categories of gaseous radioactive emissions. The evidence available suggests that the fraction of the public dose from carbon-14 is 20%-50% of the public dose from gaseous emissions. The noble gases include the xenon and krypton radionuclides formed as fission products and argon-41 formed as an activation product from argon-40. Again the evidence available suggests that, although the fraction of public dose from noble gases is small, argon-41 normally contributes more than half the public dose arising from the noble gases. This paper discusses two applications of the computer code MATLAB to assess the potential for reducing emissions of carbon-14 and argon-41.

In a CANDU reactor most of the carbon-14 is formed in the moderator system. Most of that carbon-14 is collected in a carbonate form on the anion resins of the moderator purification system. Because of gas exchange across the interfaces between the moderator heavy water and the helium gas of the moderator cover-gas system, radioactive carbon-14 in the form of carbon dioxide collects in the helium cover gas. Subsequent leakage from, or purges of, the moderator cover gas lead to the release of carbon-14.

Two potential methods of reducing the concentration of carbon dioxide in the helium cover gas are a cover-gas scrubber and an optimisation strategy for the moderator purification system. A scrubber would directly trap carbon dioxide found in the cover gas, while an optimised strategy would improve the trapping of carbonates dissolved in the moderator. This paper presents the results from a series of MATLAB calculations examining these cases.

The behaviour of carbon-14 was modelled from its formation in the moderator to its escape in gaseous emissions. The results were compared with available measurements of carbon-14 concentrations in the moderator and moderator cover gas and the weekly emissions of one CANDU 6 plant. The model predicted the concentrations of carbon-14 in the moderator and moderator cover gas successfully but underestimated the weekly emissions.

While the feasibility of using scrubbers to strip carbon-14 from the moderator cover gas has been demonstrated in tests at CRL, the results from the MATLAB analyses suggest that, with careful management of the moderator purification system, C-14 emissions can be kept to 1Ci/a. At such levels the use of scrubbers is difficult to justify but they would represent an additional line of defense.

The argon-41 is formed in several of the reactor process systems; the annulus gas system, the moderator and moderator cover-gas systems, the helium sub-system of the liquid zone control system and the primary heat-transport system. To achieve a cost-effective reduction in the argon-41 emissions it is valuable to know the contribution to the argon-41 emissions from the different process systems. To that end, AECL has been modelling the production of argon-41 from argon-40 that may be present as an impurity in the process system gas supplied to the station or from air ingress to the process system.

The modelling again uses the MATLAB package to simulate the production of argon-41 in the five process systems and the subsequent migration of argon-41 from those systems to the plant exhaust stack. The simulations suggest that the greatest contributions to the argon-41 emissions arise from the annulus gas system and the moderator cover gas system. The emissions from the latter arise from activation of the argon-40 in the moderator heavy water which crosses the heavy- water/cover-gas interfaces. These findings suggest that reducing the argon-40 impurity in the carbon dioxide of the annulus gas system and in the helium gas of the moderator cover gas would be one way to reduce the emissions of argon-41. Usually this type of reduction at source is the most cost-effective way to reduce emissions. Further study is needed to establish whether it would be more cost-effective to specify lower argon-40 levels in the helium and carbon dioxide supplied to the systems or whether efforts to control argon-40 impurity from air ingress are needed.