Evaluation of Disused Radioactive Sources in a Delay Vessel for the Storage and Disposal

a Young-Hwan KANG, *b* Dong-Soo Lee, and *a* Bong-Goo KIM
a Korea Atomic Energy Research Institute, P.O. Box 105, Yusong, Daejon, 305-600, Korea, yhkang2@kaeri.re.kr
b National Fusion Research Center, 52 Eureun Dong, Daejon, Korea

1. Introduction

An in-pile test program for the development of a high burn-up fuel is planned for the HANARO reactor. For the fuel irradiation tests an I&C system (GSF-2002) recently developed at KAERI [1] and an instrumented capsule having a double-cladded concept, will be used. If the fuel failure occurs in the system during irradiation, radioactive gaseous fission products retained in the test fuel pins will be successively released to the annulus gap between the fuel cladding and the mini-capsule tube, the gas flow tube and finally a decay vessel of the I&C system. Such a possible release from potential failure scenario could affect the safety as well as the health of the reactor workers. For this reason, a series of analyses was implemented to characterize the risk posed by radioactive sources and to make a proper disposal plan at the HANARO reactor in the event of a breach of test fuels.

2. Methods and Results

2.1 General Description of the I&C System (GSF-2002) and a capsule

The irradiation experiment system consists of 3 independent closed gas circuits, a capsule and a I&C system [2]. The binary gases flow continuously in the circuits for controlling the surface temperature of the specimens and confirming the integrity of the fuel cladding. Normally the exhaust gas passes through the open solenoid valve to the common vent line. If any fission products are detected from the fuel pin, however, isolating valve enables the gas circuit to be isolated. The exhaust gas is trapped in the holding vessel for a while and disposed to the environment through a proper procedure via a delay / trap arrangement.

For the required fuel irradiation test the design concept of the capsule, to be connected to the I&C system, is created by applying a universal principle (double containment concept) for experiments involving fissile materials in the HANARO reactor.

The test fuel to be selected is short rods of Zr-4 clad UO_2 pellets of an advanced PWR 17x17design. The irradiation at the HANARO reactor will be performed for a total of 4 cycles (one cycle lasts for 21 days with 30 MWt). The burnup of the above fuel is estimated to be around 6 GWd/Mtu, which was confirmed by the PIE data obtained from the gamma scanning method [3].

2.2 Radioactive Sources

The total fission products produced in the above test fuel pellets to be irradiated in the HANARO reactor were analyzed by the ORIGEN-2 computer code [4]. Around 700 fission products (19 radio-elements) were produced during normal operation to the burn-up of 6 GWd/Mtu.

As coolant temperature of the reactor is 40 ºC and surface temperature of the internal fuel cladding is around 200±20 ºC, a few fractions of inventory of fission gases and some of the more volatile radio-elements (e.g. krypton, xenon, cesium and iodine) could be released and accumulated to the plenum of the test rod during in-reactor operation. Most of cesium exists as a CsI and CsOH and vaporization rate of CsI below 500 ºC is negligible [5]. Thus, when the cladding is breached, 3 of 19 radio-elements such as krypton, xenon, and iodine are selected for the analysis.

The mixed gaseous fission product sources from the three fuel pins by ORIGEN 2.0 code were obtained by using the uranium mass, burn-up, R/B ratio, and leakage rates of the gaseous fission products determined from the literatures.

Calculation of source term in the analysis includes several levels of conservatism.

1) The linear power used was 425 W/cm which is equivalent to 1.15 times high to normal power calculated by using COSMOS code from HANARO Neutron Physics Group.
2) R/B ratios were determined based on the measured data by C.A. Friskney [6] and the ANS 5.4 model [7].
3) Even though the different nuclides have different leakage from the fuel in the Table 1, 20 %/10min of the leakage rate was used for the analysis to get a more conservative result.
4) In addition, a large breach of three fuel pins is assumed to occur simultaneously and all the gaseous fission products accumulated in the plenum are also released to the gas flow tubes and the decay tank.

From the source evaluation, since the gaseous fission products are more likely to be released in the event of a breach of a test fuel pin, the noble gaseous (Xe, Kr) and volatile fission products (I) are of most concern. Table 4 shows the leakage rates of three different radio-elements with high gamma energy which was evaluated based on our experimental system characteristics [8] after the cladding failure.

Table 1. Boundary condition of irradiated fuel characteristics

Irradiation Time(day)	92.0
Average Linear Power(W/cm)	426.8

Burn-Up(MWD/MtU)	8058.8
Fuel temperature(°C)	800.0
Gas Flow Rate(cc/min)	50.0
Flow Tube Diameter (inch)	0.4
Total Length of the Flow Tube (m)	23.0

Table 2. Fission gas leakage from the fuel pins for 1 minute [8].

Nuclides	4 Cycle-burned Fuel Activity (Ci)	R/B Ratio	Activity in Fuel Plenum (Ci)	Leakage Ratio(%/min)	Total Activity for 1 min.(Ci)
Kr-83M	2.53E+01	7.51E-03	1.90E-01	0.02	3.80E-03
Kr-85M	5.81E+01	1.16E-02	6.75E-01		1.35E-02
Kr-85	2.19E-01	1.51E-01	3.29E-02		6.59E-04
Kr-87	1.16E+02	6.20E-03	7.18E-01		1.44E-02
Kr-88	1.64E+02	9.22E-03	1.51E+00		3.02E-02
I-131	1.44E+02	7.47E-02	1.08E+01		2.16E-01
I-132	2.27E+02	8.32E-03	1.89E+00		3.77E-02
I-133	3.41E+02	2.50E-02	8.50E+00		1.70E-01
I-134	3.80E+02	5.16E-03	1.96E+00		3.92E-02
I-135	3.17E+02	1.80E-03	5.70E-01		1.14E-02
Xe-131M	1.41E+00	8.90E-02	1.26E-01		2.51E-03
Xe-133M	1.02E+01	3.99E-02	4.07E-01		8.14E-03
Xe-133	3.19E+02	6.09E-02	1.94E+01		3.88E-01
Xe-135	7.90E+01	1.66E-02	1.31E+00		2.63E-02

2.6 Decay Characteristics and Disposal of Radioactive Gases

The quantitative estimates of the activity concentrations and dose, which serve as key elements for characterizing the risk posed by radioactive sources, were calculated. In particular, from the analysis of a radioactive decay with time by the ORIGEN code, it was found that the relative contribution of each source depends on the time scale in Figure 1. As can be seen in Figure 1, after a storage time of about 10 months, most of the concerned gaseous nuclides with short half-lives are decayed, with one exception which is Kr-85. Thus it should be released in accordance with applicable government laws after measuring its activity in individual holding vessels.

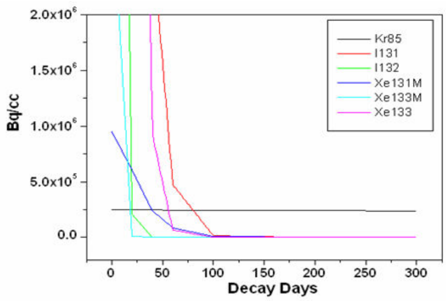

Figure 1. Radioactivity of the concerned gaseous nuclides with decay days.

3. Conclusion

From the decay characteristics of radioactive sources trapped at a delay vessel from a fuel failure the following results have been obtained:

- Accurate evaluation of the mixed sources for the new irradiation experiment system in the HANARO reactor was found to be difficult. However, several key parameters such as R/B ratio and leakage rate, which was determined based on the data collected from literature survey, were enough to calculate the gaseous fission products by ORIGEN 2.0 code and understand the risk posed conservatively by radioactive sources.
- After an adequate storage time of about 10 months, most of the concerned gaseous nuclides with short half-lives are decayed, with one exception which is Kr-85, thus it should be released in accordance with applicable government laws after measuring its activity in individual holding vessels.

This data will be used in licensing the I&C System (GSF-2002).

Acknowledgement

The present work has been financially supported by the Ministry of Science & Technology (MOST) of the Korean government under the national nuclear mid-&long- term R&D program.

REFERENCES

[1] Kang, Y.H., et al., "Current Status and the Future of the Irradiation Services in the HANARO Reactor, 2004 ANES Miami Beach, Florida U.S.A. 27-28(2004).
[2] Y.H. Kang, et al., Introduction of the I&C System for the Fuel Irradiation Tests, *Transactions of the Korean Nuclear Society Spring Meeting, JeJu Ramada Hotel, Korea, May 26-27 2005*
[3] H.M. Kim,, Private Communication(2005)
[4] D.S. Lee, Y.H. Kang, B.G. Kim, et al., The Shielding Analysis for the I&C System(GSF-2002) Development of an Instrumented Fuel Capsule", KAERI/TR-3240/2006 (2006)
[5] Ari Auvinen, et al., "Vaporization rates of CsOH and CsI in conditions simulating a severe nuclear accidents", J. Aerosol Sci. 31, No. 9(2000) 1029~1043.
[6] C.A. Friskney and J.A. Turnbull, J. Nuclear Materials, 79(1979) 184-198.
[7] W. N. Rausch, F. E. Panisko, ANS-5.4: A computer subroutine for predicting fission gas release, NUREG/CR-1213 PNL-3077, 1979
[8] Y.H. Kang, et al., Shielding Analysis and Dose Rate Evaluation for the I & C System Development of an Instrumented Fuel Capsule, 19th International Conference on Structural Mechanics in Reactor Technology, to be published.