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ABSTRACT

This method of monitoring fissile mass flow on all three legs of a blending point, where the input is high-enriched uranium (HEU) and low-enriched uranium (LEU) and the product is PEU, can yield the fissile stream velocity and, with calibration, the ^{235}U content. The product of velocity and content integrated over the pipe gives the fissile mass flow in each leg. Also, the ratio of fissile contents in each pipe: HEU/LEU, HEU/PEU, and PEU/LEU, are obtained. By modulating the source on the input HEU pipe differently from that on the output pipe, the HEU gas can be tracked through the blend point. This method can be useful for monitoring flow velocity, fissile content, and fissile mass flow in HEU blenddown of UF_6 if the pressures are high enough to contain some of the induced fission products. This method can also be used to monitor transfer of fissile liquids and other gases and liquids that emit radiation delayed from particle capture. These preliminary experiments with the Oak Ridge apparatus show that the method will work and the modeling is adequate.

INTRODUCTION

This work for developing a nonintrusive method of monitoring the mass flow of UF_6 gas was initiated in January 1995 with the support of the U.S. Department of Energy's Office of Nuclear Energy. The object of this work was to develop a method for measuring fissile mass flow from outside a pipe in which the UF_6 gas is flowing. Such a technique would be useful for monitoring the downblending of UF_6 gas of high enrichment obtained from disassembled nuclear weapons to low enrichment used to fuel light water reactors.

CONCEPT

This noninvasive method of determining the flow velocity and fissile mass flow is based on activation of the fissile stream with a modulated thermal neutron source. A source of thermal neutrons adjacent to a pipe is modulated by moving a neutron-absorbing material between the source of neutrons and the pipe. These neutrons induce fission in the fissile, stream and delayed particles emitted from fission products are detected downstream from the modulated source. The modulation of the source produces a modulation of the emission of particles downstream. This concept of monitoring fissile flow is illustrated in Fig. 1. Induced fission emits both delayed neutrons and delayed gamma rays. The ratio of delayed gamma rays[1] to delayed neutrons[2] for thermal fission of ^{235}U is >400 because ~6.5 delayed gamma rays and 0.015 delayed neutrons are emitted for each fission. Because of the high yield of delayed gamma rays in a useful time window for this application, bismuth germinate (BGO) detectors are used downstream to detect delayed gamma rays. The detector threshold for BGO is set to discriminate against the 186-keV gamma ray from ^{235}U decay. The modulation of the source produces a modulation of the gamma ray signal, which is correlated to the source. This modulation tags the gas with a time-dependent signature that can be detected downstream. The source of delayed radiation downstream is the fission products that are swept along with the gas. Cross-power spectral density (CPSD) or cross correlation function measurements are performed between signals from the detectors downstream and the modulation of the source. Cross correlation time delay or CPSD phase yields the time and thus the flow velocity since the source detector distance is known. The cross correlation and CPSD are not affected by buildup on the pipe wall but are only a function of the moving stream. The amplitude of the correlation function or CPSD is proportional to the ^{235}U content. The velocity and the amplitude give the fissile mass flow. The velocity needs no calibration, but the amplitude does. The modulation of the source is obtained by the detection of the position of the mechanism that alternately places material transparent and opaque to thermal neutrons between the source and the pipe. Noise analysis techniques have the advantage of producing quantities that do not depend on background or providing ways for removing background effects.

MODELING

A lumped parameter model is used to simulate decay and transport of delayed fission gamma ray precursors. This model solves the partial differential equations for precursor transport and for laminar flow uses, typically 25 radial rings to represent the gas. The decay of delayed gamma rays is represented by a three-group decay model based on the data of Maienschein et al.[1] Explicit models for shutter motion, source and detector field of views, correlated and uncorrelated background, and fission product range effects are included. Laminar flow reduces the signals at the detector because the rings of gas near the wall of the pipe take too long to reach the detectors, thus allowing considerable decay of the delayed radiation. If the pipe diameter is comparable to the range of fission products in the gas (a function of pressure), fission products that produce the delayed radiation embed themselves in the wall of the pipe at the source location and do not contribute to the detector response. These fission product range effects have been incorporated with mass, energy, straggling, etc., dependence using available data for range of fission fragments.[3] The laminar flow and precursor decay models have been verified against Monte Carlo flow simulations. The induced fission in the UF_6 gas, backgrounds, and detection probabilities are obtained from Monte Carlo calculations using MCNP-DSP.[4,5]

OAK RIDGE APPARATUS

The Oak Ridge apparatus uses a moving ^{235}U fission chamber (80 mg ^{235}U per centimeter of length) to simulate a flowing gas. This chamber is 8 ft long with position sensitivity in 1-ft sections when operated as a fission counter. It is primarily designed as a counter, and this feature can be used to measure induced fission. This apparatus is shown in Fig. 2. This apparatus simulates all the physical phenomena in this type of system except fission product range effects and laminar flow. Since the uranium deposit in the chamber is fixed, it simulates plug flow or turbulent flow where the gas moves along as a lump. The fission chamber is moved in an aluminum half-pipe 24 ft long by a motor drive connected to the chamber through a source moderator block that contains ^{252}Cf sources. The total measured dose at 1m from the moderator block is ~4 mrem/h with six 0.7-μg ^{252}Cf sources in the block (~4.2 μg). The end limit travel positions of the chamber are set by limit switches. For the present apparatus the neutron absorber on the shutter is cadmium, but the preferred material is ^{6}Li to minimize capture gammas and background.

For the experiments reported here, four BGO detectors 4-in-diam. and 2-in-thick were located 2 m from the source moderator block. The use of this apparatus is as follows: The fission chamber is located to the left in Fig. 2. The chamber starts moving at a selected velocity; the shutter opens, inducing fission in the ^{235}U. After a specified period of time, the shutter closes and the chamber moves through the detectors. Counts are recorded as a function of time during the motion of the chamber and slightly thereafter. Shortly after the chamber activates the end-of-travel limit switch, it stops and reverses direction. When it reaches the beginning-of-travel limit switch, the cycle is repeated. Since the ^{235}U fission chamber is recycled through the system, there is a buildup of activity in the chamber that would not occur in the application to UF_6 gas flow. This additional phenomenon has been incorporated in the modeling and can be significant when the velocity is high. To enhance source effects, the fission chamber can be held stationary during a relatively long exposure (e.g., 10 s). To look at reduced source effects, any number of the six 0.7-μg ^{252}Cf sources can be removed. The detector response obtained with 4.2 μg of ^{252}Cf is shown in Fig. 3 for two velocities (6 and 12 cm/s). Despite the considerable decay of the delayed gamma rays in this 33-s time interval for the slower speed, the peak in the detector response is obvious, and the transport time is clearly defined by this measurement. For this particular set of tests, the chamber was held stationary for 10 s with the shutter open before the motion was initiated to simulate the effect of a larger source. For shorter exposures or for less californium source intensity, the peaks are not as obvious but can be obtained by advanced signal processing methods.

CONCLUSIONS

This method of monitoring fissile mass flow on all three legs of a blending point, where the input is high-enriched uranium (HEU) and low-enriched uranium (LEU) and the product is PEU, can yield the fissile stream velocity and, with calibration, the ^{235}U content. The product of velocity and content integrated over the pipe gives the fissile mass flow in each leg. Also, the ratio of fissile contents in each pipe: HEU/LEU, HEU/PEU, and PEU/LEU, are obtained. By modulating the source on the input HEU pipe differently from that on the output pipe, the HEU gas can be tracked through the blend point. This method can be useful for monitoring flow velocity, fissile content, and fissile mass flow in HEU blenddown of UF_6 if the pressures are high enough to contain some of the induced fission products. This method can also be used to monitor transfer of fissile liquids and other gases and liquids that emit radiation delayed from particle capture. These preliminary experiments with the Oak Ridge apparatus show that the method will work and the modeling is adequate.

REFERENCES

1. F. Maienschein, R. Peelle, W. Zobel, and T. Love, Proceedings of 2nd International Conference Geneva 15, 366 (1958); see also later report in Proceedings of International Conference on Pile Neutron Research in Physics, IAEA, Vienna, 1960.

2. G. R. Keepin, T. F. Wimett, and R. K. Ziegler, Phys. Rev. 107, 1044 (1957). A more complete account is given in J. Nucl. Energy 6, 1 (1957).

3. L. C. Northcliffe and R. F. Schilling, Nuclear Data Tables, Vol. 7, No. 3-4, Academic Press, NY, NY (1970).

4. T. E. Valentine and J. T. Mihalczo, "MCNP-DSP: A Neutron and Gamma Ray Monte Carlo Calculation of Source-Driven Noise-Measured Parameters," Ann. Nucl. Energy 23, (1), 1271-1287 (1996).

5. T. E. Valentine and J. T. Mihalczo, "Validation of the Monte Carlo Code MCNP-DSP," Annals of Nuclear Energy (1996, in press).

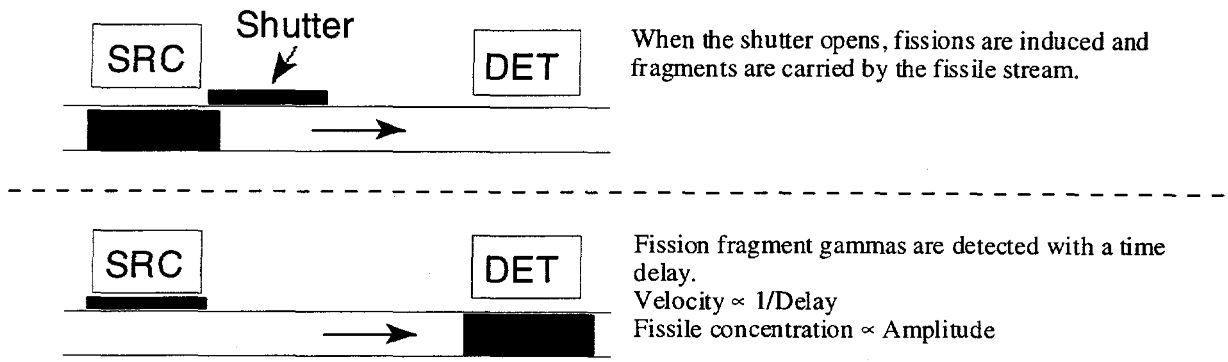

Figure 1. Illustration of Fissile Mass Flow Measurement Concept

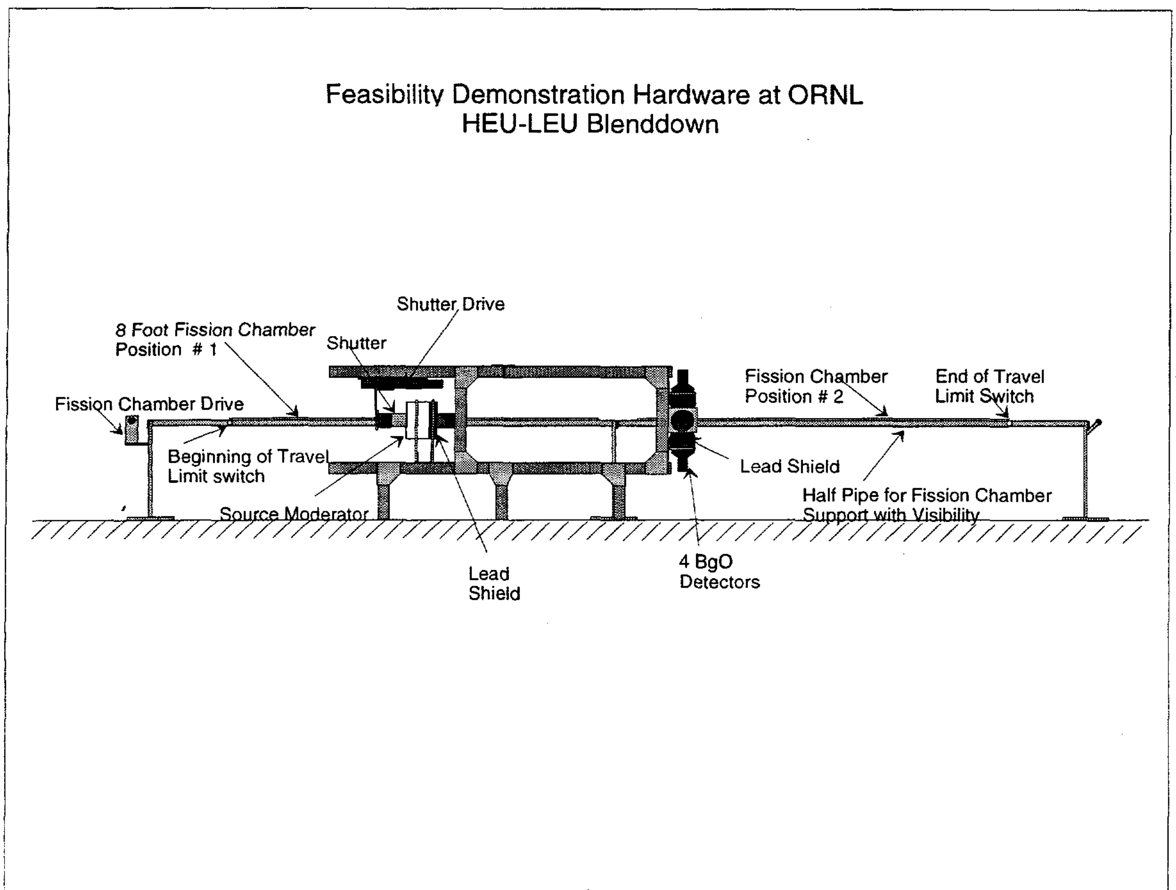

Figure 2. Illustration of Feasibility Demonstration Hardware at ORNL HEU-LEU Blenddown

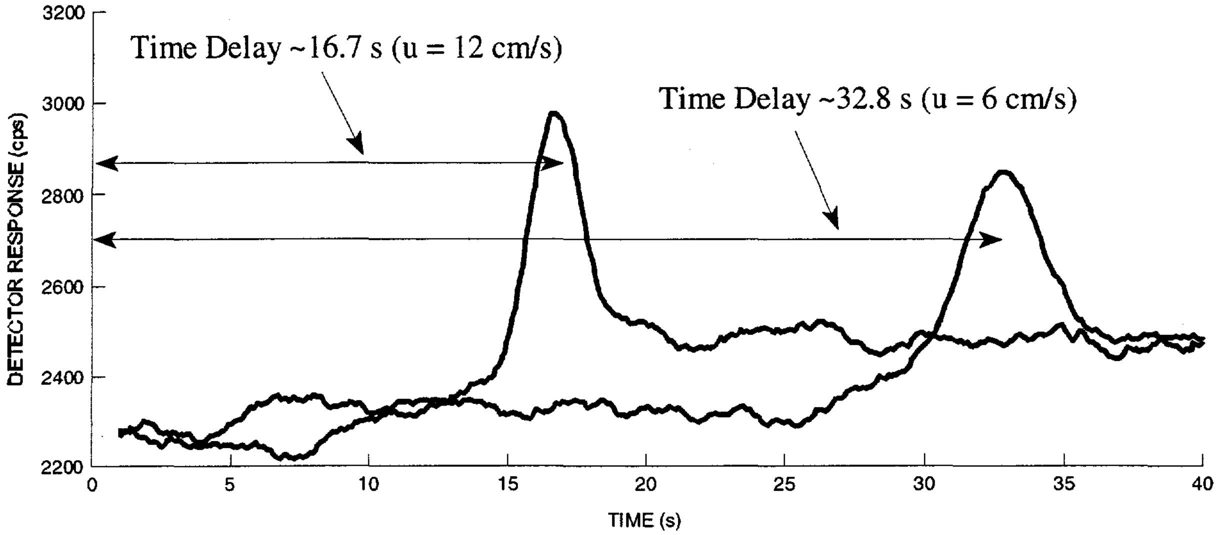

Figure 3. As this Sample Results from ORNL Tests Illustrate, Measured Time Delay is Inversely Proportional to Velocity