HARDWARE IMPLEMENTATION OF THE ORNL FISSILE MASS FLOW MONITOR

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INTRODUCTION

This paper provides an overall description of the implementation of the Oak Ridge National Laboratory (ORNL) Fissile Mass Flow Monitor, which is part of a Blend Down Monitoring System (BDMS) developed by the U. S. Department of Energy (DOE). The Fissile Mass Flow Monitor is designed to measure the mass flow of fissile material through a gaseous or liquid process stream. It consists of a source-modulator assembly, a detector assembly, and a cabinet that houses all control, data acquisition, and supporting electronics equipment. The development of this flow monitor was first funded by DOE/NE in September 1995, and an initial demonstration by ORNL was described in previous INMM meetings. This methodology was chosen by DOE/NE for implementation in November 1996, and the hardware/software development is complete. Successful BDMS installation and operation of the a complete BDMS has been demonstrated in the Paducah Gaseous Diffusion Plant (PGDP), which is operated by Lockheed Martin Utility Services, Inc. for the US Enrichment Corporation and regulated by the Nuclear Regulatory Commission (NRC). Equipment for two BDMS units has been shipped to the Russian Federation (R.F.)

BACKGROUND

Recent HEU Transparency agreements between the United States (US) and the R. F. provide for the monitoring of the blending of highly enriched uranium (HEU) at an assay of ~90% with low enrichment blend stock uranium (LEU) at an assay of ~1.5% to produce reactor-grade material at an assay of ~4% to be used in U.S. nuclear power plants. The BDMS has been developed to provide unattended monitoring of the HEU blending operations at the R.F. facilities. It is configured to monitor the mass flow rate and $^{235}$U isotopic enrichment of gaseous UF$_6$ in these three separate flow streams. The ORNL Flow Monitor component of the BDMS has been developed by the Oak Ridge National Laboratory. It measures the mass flow rate of gaseous UF$_6$ flowing through a process pipe, without requiring direct contact with the gas in the pipe. The ORNL Flow Monitor also traces fission products generated in the HEU stream through the blending operation and into the product LEU stream, thus confirming HEU blending. The instruments that measure flow and enrichment are placed around existing process piping and do not require direct contact with the UF$_6$ gas or piping penetrations for operation of the BDMS.

OPERATING PRINCIPLES OF ORNL FISSILE MASS FLOW MONITOR

The ORNL Flow Monitor has two functions: measure the mass flow rate of fissile material in a process pipe and trace the flow of the fissile material from the HEU leg to the product LEU leg. To achieve these functions, the Flow Monitor induces fissions in the fissile stream and detects the delayed gamma rays emitted by fission fragments at a downstream detector location (See Figure 1). The induced fissions are modulated using a neutron-absorber shutter to create a time signature that is detected by the downstream detectors. The Flow Monitor determines the fissile mass flow rate by relying on two independent measurements: (1) the time required for the fission fragments to travel along a given length of pipe, which is inversely proportional to the fissile material flow velocity, and (2) an amplitude measurement, which is proportional to the fissile concentration (e.g., grams of $^{235}$U per length of pipe). Fissile traceability is

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accomplished by detecting the presence of time-modulated fission fragments in the product LEU process gas at a detector downstream of the blending “Tee.”

MAJOR COMPONENTS OF THE ORNL FLOW MONITOR

Figure 1 shows a system block diagram of the three major Flow Monitor components: the cabinet, the source-modulator assembly, and the detector assembly, and Table 1 contains a list of relevant component attributes for the ORNL Flow Monitor. The Cabinet provides power conditioning and distribution, control, and data acquisition and processing. Figure 2 shows a picture of the full BDMS as installed in PDGP during the demonstration measurements. The Flow Monitor cabinet is the left section in this picture; the right section controls the enrichment monitor component of the BDMSD.

Figure 3 shows all the Flow Monitor pipe-mounted components for a single fissile flow stream. The Source-Modulator assembly includes the $^{252}$Cf sources, a polyethylene moderator, a neutron absorber shutter, and its associated shielding. Figure 4 through Figure 6 show the source modulator in different stages of assembly. The moderator subassembly, which contains the $^{252}$Cf sources, can be seen in Figure 4. The moderator is surrounded by lead and polyethylene shielding (see Figure 5 and Figure 6) to minimize the radiation dose. This dose has been measured for the configuration shown in Figure 3. The dose rate is less than 0.3 mRem/h at any point 1 m away from the Source Modulator, and less than 10 mRem/h at any point in contact with the equipment. These dose rates meet all applicable requirements for installation.

The detector assembly is comprised of four Bismuth Germinate Oxide (BGO) detectors that surrounding the pipe. The detector crystals and the photo-multiplier tubes are surrounded by lead shielding to minimize room-background effects (see Figure 7 through Figure 9). In addition, to minimize the radiation background induced by the $^{252}$Cf source, a three-inch circular gamma shield is placed upstream, as seen in Figure 7.

Each detector subassembly is fitted with a detector-interface-electronics card (see Figure 8), which contains the signal conditioning and discrimination amplifiers. The interface card also includes an on-board computer, which controls its operation and collects detector counts that are periodically downloaded to the main computer in the cabinet for processing.

LICENSING ISSUES FOR PGDP IMPLEMENTATION

The BDMS, which includes the ORNL Flow Monitor, have been installed and its operation has been demonstrated in PGDP. Since PGDP is an operating nuclear facility licensed by the U.S. NRC, the implementation of the demonstration was reviewed thoroughly prior to being approved. This review was performed to ensure that the safety implications of the demonstration were adequately addressed by the plant-change review process (in accordance with the NRC regulations in 10 CFR 76.68). This review identified two safety concerns that had to be addressed: the first one was the addition of process piping to the PGDP cascade, and the second one was the increase in the radioactive source possession limits for the plant site (to cover the presence of the $^{252}$Cf sources). The review concluded that neither the Flow Monitor equipment nor its operation resulted in significant safety questions. The plant change review process determined that the changes to the cascade piping, the use of $^{252}$Cf sources on site, and the operation of the Flow Monitor equipment did not constitute an unreviewed safety question (USQ). All of the work required to implement the PGDP demonstration was within the bounds of the plant’s Safety Analysis Report (SAR). Hence, the installation and operation of the demonstration at PGDP was approved by the site operator following the standard NRC regulation process described in 10 CFR 50.59.
SUMMARY

A Fissile Mass Flow Monitor has been developed to implement HEU Transparency agreements as part of a Blend Down Monitoring System. The Flow Monitor has been implemented in hardware and software. Its operation has been demonstrated successfully during extended tests at the Paducah Gaseous Diffusion Plant.

Table 1. Major Flow Monitor attributes for a three-stream blending T.

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<thead>
<tr>
<th>COMPONENT</th>
<th>QUANTITY</th>
<th>VALUE</th>
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<tbody>
<tr>
<td>Radioactive sources ($^{254}$Cf)</td>
<td>12</td>
<td>2.2 mCi (4 μg)</td>
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<tr>
<td>Weights:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cabinet</td>
<td>1</td>
<td>~200 kg</td>
</tr>
<tr>
<td>Source Modulator</td>
<td>3</td>
<td>740 kg</td>
</tr>
<tr>
<td>Detector Assembly</td>
<td>3</td>
<td>195 kg</td>
</tr>
<tr>
<td>Maximum Power (220 V, 60 Hz)</td>
<td></td>
<td>4.8 kW</td>
</tr>
<tr>
<td>Pipe Size</td>
<td></td>
<td>4.25 inch OD</td>
</tr>
</tbody>
</table>

Source and Modulator Assembly (HEU)  
Moderator (Polyethylene)  
Source holder and $^{254}$Cf Source (4 spaced at 90 deg)  
Gamma Shield  
Detector Box (4 spaced at 90 deg)  
Shutter (With Window)  
Gamma (>300 KeV)  
Limit Switches

Detector Assembly (HEU)  
BGO Scintillator Photomultiplier  
High-Voltage+  
Gain Set  
Threshold Set  
Shaping Amplifier  
Controller  
To Other 3 HEU Detectors

Figure 1. Flow Monitor System Block Diagram
Figure 2. Blend Down Monitoring System (Flow and Enrichment Monitors) in the Paducah Gaseous Diffusion Plant during the demonstration measurements.

Figure 3. Installed Source-Modulator and Detector Assemblies with supplemental neutron and gamma shields.
Figure 4. Partially assembled shielding for the source modulator, and shutter assembly.

Figure 5. Lead and partially assembled polyethylene shielding with source modulator installed.

Figure 6. Final assembly of polyethylene shielding for source modulator assembly.
Figure 7. Flow Monitor detector assembly

Figure 8. Detector detail showing the signal-conditioning interface card.

Figure 9. Detector detail, showing the BGO crystals and their lead shields positioned around the pipe.