The $^{252}$Californium Shuffler

The $^{252}$Cf shuffler is a versatile nondestructive assay (NDA) instrument that has been used for measuring uranium in a wide variety of forms, ranging from large spent fuel assemblies to small amounts of scrap and waste. Shufflers are relatively insensitive to measurement bias caused by matrix materials and consequently provide one of the most accurate methods available for measuring uranium waste. Because of ruggedized design and reliability of components, shufflers are well suited for plant operating conditions.
The principles of shuffler operation are illustrated in the drawings above. When the $^{252}$Cf source is in the interrogation position, neutrons from the source induce fissions in the sample. After a few seconds of interrogation, the $^{252}$Cf source is quickly removed to a shielded position, and delayed neutrons emitted by fission fragments are counted. The number of delayed neutrons emitted is proportional to the amount of fissionable material present in the sample. The cycle of interrogation and delayed neutron counting can be repeated many times to obtain good statistical precision. The shuffler design shown in the cut-away drawing on the cover was optimized for measuring 55-gallon waste barrels.

To obtain a more uniform response from nuclear materials at different locations in the barrel, the shuffler rotates the barrel and the $^{252}$Cf source scans the length of the barrel during interrogation. In the active mode, the shuffler responds to all fissionable isotopes present in the sample. By shielding the $^{252}$Cf source exceptionally well, shuffler hardware can also serve as a passive neutron counter. Passive neutron coincidence counting is used to assay spontaneously fissioning isotopes such as $^{240}$Pu. Following this approach, new active/passive barrel shufflers are capable of measuring small amounts of $^{235}$U in the active mode and $^{240}$Pu in the passive mode.
Active-Passive Barrel Shuffler Characteristics

\textsuperscript{252}Cf Source and Shield
- Source strength: $8 \times 10^4$ n/s
- Source half-life: 2.6 yr
- Radiation shielding: 2 tons
- Radiation level: 1 mR/h at 1 m from source shield
- Irradiation cycle: 11 s
- Count cycle: 7 s
- Source transfer time: 0.4 s

Sample Chamber
- Detectors: 64 \textsuperscript{3}He tubes
- Detection efficiency: 17.5%
- Radiation shielding: 4 tons
- Barrel rotation speed: 3 rpm
- Liner: cadmium
- Inside diameter: 30 in.

Measurement Capability
- Measurement time: 1000 s
- \textsuperscript{235}U detection sensitivity (active): 300 mg
- in thermal mode (active): 20 mg
- \textsuperscript{240}Pu detection sensitivity (passive): 4 mg
- Accuracy: 15% for waste barrels

Active/passive barrel shuffler characteristics are shown in the table at the left. A \textsuperscript{252}Cf source of 0.35 mg emits $8 \times 10^8$ neutrons per second. Shielding (consisting of tungsten, high-density polyethylene, and boron-loaded polyethylene) is used to limit the radiation dose rate outside the shuffler. The optimum interrogation time and count time for each cycle depend on the type and amount of material to be measured. A large number of \textsuperscript{3}He tubes surrounding the measurement chamber gives a high neutron counting efficiency. Detection sensitivities quoted in the table correspond to the smallest mass of bare material that gives a count rate 3 sigma above neutron background at sea level. The \textsuperscript{235}U detection sensitivity can be lowered to 20 mg if the cadmium liner is removed from the measurement chamber so that neutron interrogation is performed in the thermal mode. Accuracy depends on the distribution of fissionable material within the barrel, on the effect of matrix materials, and on the suitability of the NDA standards used to calibrate the instrument. For waste barrels that can be separated by type of matrix, the assay accuracy is estimated to be plus or minus 15% (1 sigma).

Shuffer Electronics

The block diagram at the right shows the electronic components of an active/passive shuffler. The \textsuperscript{252}Cf source is attached to a Teleflex cable, which is driven by a stepping motor. Safety sensors verify the position of the source and ensure that the doors are closed before the source is lowered into the measurement chamber. Instrument operation is controlled by a small computer. Software provides measurement control, routine assay, and data archiving.
Applications of Los Alamos Shufflers

<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
<th>Material Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Alamos</td>
<td>Prototype</td>
<td>Uranium solids, MOX, U ore</td>
</tr>
<tr>
<td>Savannah River</td>
<td>Can shuffler</td>
<td>Uranium scrap, sweepings</td>
</tr>
<tr>
<td>Idaho FAST</td>
<td>Dual interrogator</td>
<td>Spent fuel assemblies, hot waste</td>
</tr>
<tr>
<td>Los Alamos</td>
<td>Compact shuffler</td>
<td>UF₆, MOX samples</td>
</tr>
<tr>
<td>Los Alamos</td>
<td>Barrel shuffler</td>
<td>Uranium solids, waste</td>
</tr>
<tr>
<td>Dounreay, Scotland</td>
<td>Spent fuel shuffler</td>
<td>Leached hulls, reprocessing waste</td>
</tr>
<tr>
<td>Savannah River</td>
<td>In-cabinet shuffler</td>
<td>HEU finished product</td>
</tr>
<tr>
<td>Savannah River</td>
<td>In-cabinet shuffler</td>
<td>High-density HEU scrap</td>
</tr>
<tr>
<td>Savannah River</td>
<td>Barrel shuffler</td>
<td>High-density HEU waste</td>
</tr>
<tr>
<td>Portsmouth</td>
<td>Active/passive barrel shuffler</td>
<td>HEU &gt;20%, alumina, UF₆, tails</td>
</tr>
<tr>
<td>Idaho WINCO</td>
<td>In-line shuffler</td>
<td>Hot uranium solutions</td>
</tr>
<tr>
<td>Portsmouth</td>
<td>Active/passive barrel shuffler</td>
<td>HEU &lt;20%, alumina, UF₆, tails</td>
</tr>
</tbody>
</table>

Additional Sources of Information (listed chronologically)


