Nuclide Determination of TRIGA Fuel Elements by Gamma Spectroscopy

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ABSTRACT

Fuel elements used at the TRIGA Mark-II reactor located at Atominstitut in Vienna were examined by gamma spectroscopy along the vertical axis. These fuel elements have been used in a TRIGA reactor core in Japan 26 years ago and were transferred through interim storage at Idaho National Lab (INL) to the TRIGA reactor Vienna in October 2012. Therefore only the long lived fission product Cs-137 was expected. For this investigation the fuel elements (FE) were transported from the reactor core with the fuel transfer cask and placed into the fuel scanning device.
The device includes a vertical lifting system to move the fuel in front of a collimator hole for axial gamma scanning using a HP-Ge Gamma detector. Each FE was investigated for peaks and the strongest emission line was detected at 661 keV belonging to Cs-137. Some FE also contained Co-60, Ce-144 and Zr-95. Gamma spectra were recorded every 10 mm along the fuel rod axis resulting in the vertical distribution of the fission products. The activity concentration was calibrated using a standard calibration source of known activity to determine the maximum activity and consequently the burn-up of each fuel element.

1. Introduction

The Vienna TRIGA-Mark II reactor operated by the Atominstitut of the Technical University Vienna is located in Vienna Prater and remains the only operational research reactor in Austria. TRIGA is an abbreviation for "**T**raining, **R**esearch, **I**sotope Production, **G**eneral **A**tomics". This reactor was installed from 1959 to 1962 by the US company "General Atomics" and first went critical on March 7, 1962. Since this date the reactor has been operated without any major problems about 220 days per year. It is a swimming-pool type reactor using standard TRIGA fuel elements. In the past, three different fuel types were used in the core, in November 2012 all these fuel elements were returned to the USA and replaced by low burnt SST clad, 19,8 % enriched TRIGA fuel elements.

On one hand the present work investigates three fuel elements from the current core configuration: The fuel elements were loaded into the Vienna TRIGA core in November 2012, before they were used for a very short period in the Musashi TRIGA reactor in Japan and then they were shipped in 1989 to the Idaho National Lab (INL). Those FE are numbered 9905, 9915 and 9932. These FE were part of the core conversion performed in November 2012 [5] with support of the International Atomic Energy Agency (IAEA) and the United States Department of Energy (DOE).

From August 27 till September 14, 2012, experts from the Atominstitut performed an optical inspection of very low burnt 104-types SST clad LEU elements stored at the INL. Out of a list of one hundred and twenty (120) fuel elements, seventy-seven (77) have been chosen. Seventy-five (75) FE(s) were chosen from the former TRIGA reactor in Musashi, Japan, and two (2) FE(s) from the former TRIGA reactor in Cornell, USA.

- 75 FE came from the reactor in Musashi, Japan
  - This reactor was in operation from January 30, 1963 until March 26, 1985 with Al cladded fuel elements, afterwards the reactor operated from July 25, 1985 till December 21, 1989 with SST cladded fuel elements, the average burn up is in the range below 1%

- 2 FE came from the reactor at Cornell University, USA
  - Initial criticality January 12, 1963, shut down date April 21, 2003,the burn up is slightly above 1%

Furthermore three additional fuel elements from the current core had been measured which belong to the ATI and were installed in the reactor core for several years.

On the other hand eight fuel elements were investigated which had cooled down in the pool storage racks inside the reactor tank for several years. The operational data are shown in Tab 2.

The objective of this work was to gamma-scan some of these fuel rods and to determine the type and amount of individual fission products. For this purpose an existing Fuel Scanning Machine (FSM) developed by the ATI [7] was used in combination with a gamma ray detector to scan the vertical axis of the fuel rods. The raw measurement data of those scans were then transferred to a special application module to display the results in form of gamma spectra. The results were investigated for peaks at certain energies, traceable to certain fission products contained in the fuel elements due to the fuel history.

The detector calibration was done with several different known gamma sources to provide reliable results. From the obtained spectra it is possible to calculate the exact burn-up of each measured fuel element by comparing the data with an available TRIGA fuel sample with exactly know burn-up. This method of fuel burn-up determination has been published previously in /2,5/.

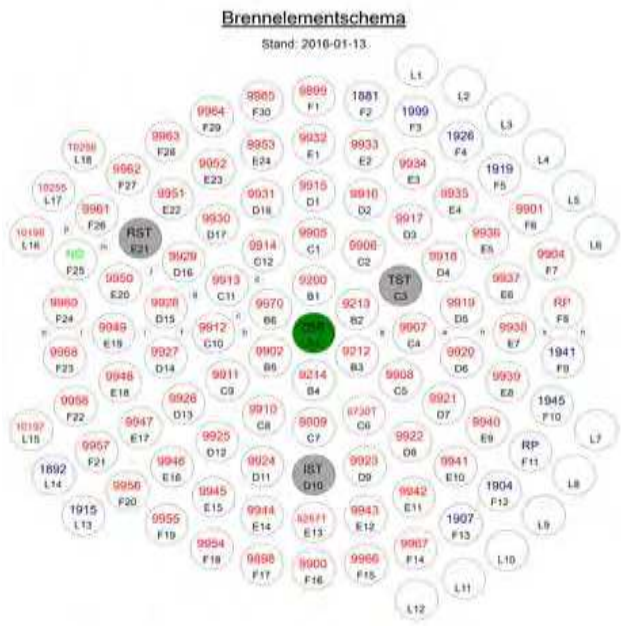

Fig 1: Schematic overview of the fuel element positions

All the investigated fuel elements are of the type 104: their geometrical and material specifications are shown in Table 1.

Fuel element type	Type 104
Fuel moderator material	U-Zr-H1,65
Uranium content (wt. %)	8.5
Enrichment (%)	19,8
Erbium content (%)	0
Diameter x length of fuel meat (cm)	3.63 x 38.1
Graphite reflector length (cm)	8.81
Cladding material	304 SS
Cladding thickness (mm)	0.51

Tab 1: Geometrical and material specifications of the FE Type 104

FE No.	Detetced Nuclides	Date of last Irradiation	Date of measurement	Current position
9972	137-Cs	21/12/1989	12/01/2015	Stored
9973	137-Cs	21/12/1989	13/01/2015	Stored
9974	137-Cs	21/12/1989	14/01/2015	Stored
10255	137-Cs, 60-Co	21/04/2003	15/01/2015	Stored
10256	137-Cs, 60-Co	21/04/2003	21/01/2015	Stored
10197	137-Cs, 60-Co	27/04/2012	26/01/2015	Stored
10198	137-Cs, 60-Co	27/04/2012	28/01/2015	Stored
9959	137-Cs, 60-Co, 95-Zr, 144-Ce	14/04/2014	29/01/2015	Stored
9213	137-Cs, 60-Co, 95-Zr, 144-Ce	25/03/2015	01/12/2015	B2
9214	137-Cs, 60-Co, 95-Zr, 144-Ce	25/03/2015	02/12/2015	B4
9200	137-Cs, 60-Co, 95-Zr, 144-Ce	25/03/2015	02/12/2015	B1
9905	137-Cs, 60-Co, 95-Zr, 144-Ce	25/03/2015	03/12/2015	C1
9915	137-Cs, 60-Co, 95-Zr, 144-Ce	25/03/2015	03/12/2015	D1
9932	137-Cs, 60-Co, 95-Zr, 144-Ce	25/03/2015	03/12/2015	E1

Tab 2: Measured Fuel Elements.

3. Experimental Setup

The fuel elements were transferred from the core with a special lead transfer cask to the "Fuel Scanning Machine" (FSM) by a crane. This machine (Fig.2) allows scanning the elements along the vertical axis and to raise the fuel rods exactly into the desired measurement position. Data were acquired in steps of 10 mm. A collimator concentrates the gamma rays of the element directly to the gamma detector. In the experimental setup a High Purity Germanium (HP-Ge) detector was used. A preamplifier allows to shape the detected decay into an electronic signal that can be further processed. Due to high count rates of the fission product decays a „Multi Channel Analyzer" (MCA) had to be used, which rejects electronic noise and background radiation and converts the analog signal into a digital signal. The incoming signals are separated into groups with similar energy and are separated into channels. 8192 channels were used for a more detailed result. [1, 3]

However, only one signal at a time can be processed, therefore a gate closes during the conversion process. The closed time is called „Dead Time" (DT). Incoming signals during DT cannot be processed. To accommodate to this circumstance the measurement time („Real Time" RT) gets longer to accomplish the planned measurement time („Live Time" LT)

$$RT = LT + DT$$

With this setup gamma spectra can be transferred to the computer, by plotting the count rates per channel. After calibrating the detector by a source of known activity, each channel can be clearly identified by its energy. The basic equation is given by:

$$\mathrm{E} = \mathrm{S} * \mathrm{Channel} + \mathrm{O}$$

S is referred as the Slope and O is the Offset.

Fig 2: The experimental Fuel Scanning Machine (FSM) set up developed at Atominstitut

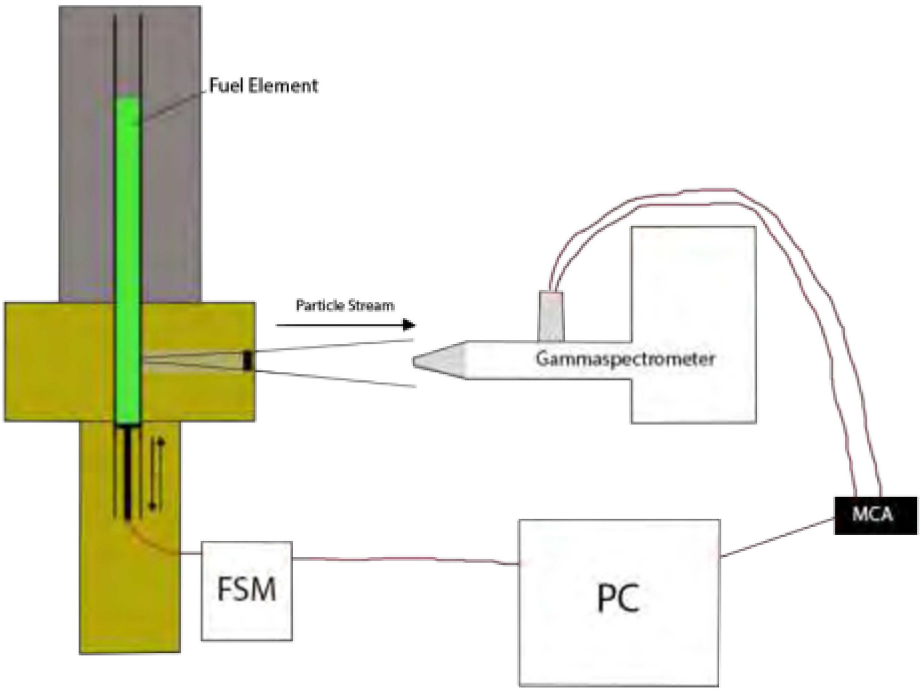

Figure 3 shows a typical measured gamma spectrum which includes peaks of Cs-137, Zr-95 and Co-60, this fuel element was the last time exposed to operation on April 14th 2014 with approx. 8 month of decay time.

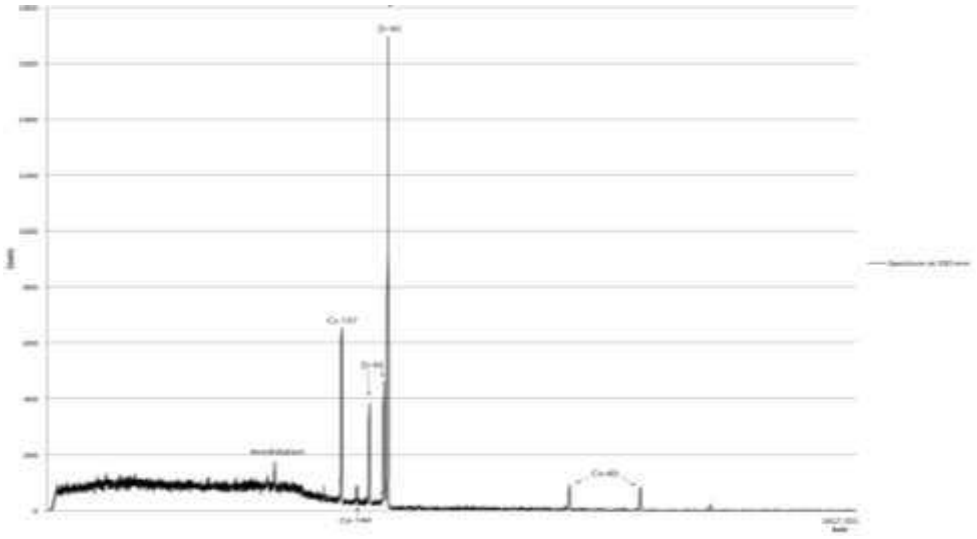

Fig 3: Measured Gamma Spectrum of fuel element 9959

4. Results and Discussions

Due to the fuel cooling time of about 26 years, only Caesium -137 was found in the fuel rods 9972 to 9974 as a fission product. The spectra from the fuel elements 10255, 10256, 10197 and 10198 furthermore contain Co-60, caused from their activated cladding material. All other measured fuel rods contained further nuclides due to a shorter decay time such as Zr-95 and Ce-144. Figure 4 presents the axial distribution of Cs-137 along the length of the measured FE 9200. The axial Cs-137 profile (i.e. maximum in the centre and decreases along the length) follows the axial flux distribution. The two small peaks at the upper and lower end of the FE show the effect of two axial graphite reflectors at both ends of the fuel meat (see Figure 4).

As expected fuel elements with similar history provide similar data. Those fuel rods which were stored inside the reactor tank for almost 26 years emit much lower radiation levels and mostly at 661 keV belonging to Cs-137. Fuel elements with SST cladding material are emitting Co-60 as well originating from cobalt traces in the stainless steel cladding.

Three fuel elements imported from the Musashi Reactor (9905, 9915, 9932) show a decreasing radiation level due to a decreasing flux density at the outer parts of the reactor core, correlating to their position at B1-E1 (Fig 1.). In Table 3 all maxima of Cs-137 activities (at 350 mm measurement position) are given.

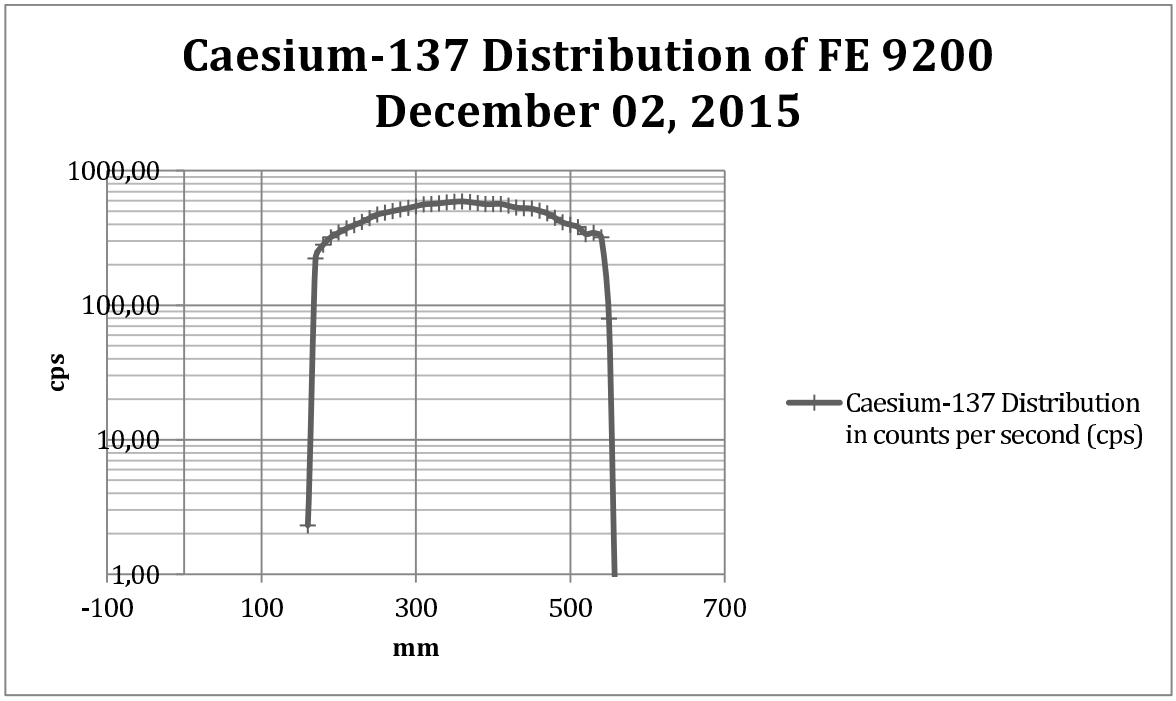

Fig 4: Result-spectrum of FE 9200 - Cs-137 distribution along vertical axis

FE No.	Max. Activity [Bq]	Date Of Measurement
9972	3,84 E+07	12/01/2015
9973	2,11 E+07	13/01/2015
9974	4,83 E+07	14/01/2015
10255	1,75 E+08	15/01/2015
10256	1,70 E+08	21/01/2015
10197	1,03 E+09	26/01/2015
10198	6,48 E+08	28/01/2015
9959	1,56 E+08	29/01/2015
9213	6,01 E+08	01/12/2015
9214	6,54 E+08	02/12/2015
9200	1,93 E+09	02/12/2015
9905	7,53 E+08	03/12/2015
9915	6,95 E+08	03/12/2015
9932	5,17 E+08	03/12/2015

Tab 3: Maxima of Cs-137 Activities

5. Conclusion

During the period from initial start-up in 1962 to April 2012 the TRIGA reactor Vienna operated with a mixed core using three types of fuel elements such as LEU-Al clad type 102, LEU-SST clad 104 and HEU-FLIP-SST clad fuel elements. During this period the FSM helped to verify the fuel burn-up and to optimize the fuel utilization. This results of these experiments were published in [2,6].

After the fuel swap between Atominstitut and Idaho National Lab. in October 2012 /4/ the TRIGA core is now composed of identical type LEU-SST clad type 104 fuel elements. However these fuel elements have different irradiation histories as described in this paper. In order to optimize their lifetime in the reactor core, fuel scanning measurements have been carried out, the results allow to determine the individual TRIGA fuel burn-up and to plan reshuffling of individual fuel elements within the 87 core positions available in the TRIGA core Vienna to achieve a maximum reactor operation lifetime.

6. References

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