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VVER-1000 SFAT— SPECIFICATION OF AN INDUSTRIAL PROTOTYPE

Interim report on Task FIN A 1073 of the Finnish Support Programme to IAEA Safeguards

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ABSTRACT

The project to develop a Spent Fuel Attribute Tester (SFAT) for Ukrainian VVER-1000 facilities is going on under the Task FIN A 1073 of the Finnish Support Programme to the IAEA safeguards.

In the SFAT method [1] the verification is based on an unambiguous detection of gamma radiation of the fission products. This is implemented by detecting the radiation emitted by a fuel assembly with a mobile gamma-spectroscopic instrument consisting of a collimator arrangement and a detector unit. The fuel assemblies stored in a wet storage are not moved during the verification measurement. The principal target is the radiation characteristic to ^{137}Cs. For short cooled assemblies also ^{144}Pr can be used as the target fission product nuclide.

The generic IAEA SFAT concept has been adapted to the special conditions at the Ukrainian facilities. The requirements of the End User (IAEA), the State Nuclear Safety Authority (NRA) and the facilities have been taken into account and included in the specifications.

Since the issuance of the first interim report [2], additional measurements were conducted at the Zaporozhye NPP to ensure the feasibility of the suggested measurement geometry and to test whether the SFAT device could be operated using the refuelling machine.

A clear answer to the optimal measurement geometry and the detector choice was also obtained during this first phase of the task.

Basing on the measurement results and the operational experience, the technical specifications for an industrial SFAT prototype are formulated.

The technical specifications presented in this report and in the previous report [2] have been approved by the Ukrainian State Authority and one of the facility operators, the Zaporozhye NPP. A procedure has been started for getting the approval of the other Ukrainian operators.

РЕФЕРАТ

Проект по разработке тестера отработавшего топлива (SFAT) для украинских АЭС с реакторами ВВЭР-1000 выполняется в рамках задачи FIN A 1073 финской программы поддержки гарантий МАГАТЭ.

В методе SFAT [1] верификация основана на однозначной регистрации гамма излучения продуктов деления. Это осуществляется путем регистрации излучения топливной сборки с помощью перемещаемого гамма спектроскопического устройства, состоящего из узла коллимации и блока детектирования. Топливные сборки хранятся в мокром хранилище и не перемещаются во время проведения измерений для верификации. Основной целью является излучение, характерное для ^{137}Cs. Для сборок с малым временем выдержки ^{144}Pr также может являться определяемым продуктом деления.

Общий подход МАГАТЭ адаптирован к особенностям украинских установок. Требования конечного пользователя (МАГАТЭ), государственного компетентного органа по ядерной безопасности (ГАЯР) и установок приняты во внимание и включены в спецификацию.

После выхода первого промежуточного отчета [2] были проведены дополнительные измерения на Запорожской АЭС для проверки определенной геометрии измерений и изучения возможности перемещения устройства SFAT с использованием перегрузочной машины.

В течение первой фазы задачи был также получен ясный ответ на вопрос о выборе детектора и оптимальной геометрии измерений.

На основании результатов измерений и опыта работы разработано техническое задание на опытный образец устройства SFAT.

Техническое задание, представленное в настоящем отчете и в предыдущем отчете одобрены Государственным компетентным органом и одной из эксплуатирующих организаций. Начат процесс получения одобрения от других украинских эксплуатирующих организаций.

CONTENTS

1 INTRODUCTION

The International Atomic Energy Agency (IAEA) verifies spent fuel for safeguards purposes. Usually the verification is performed using an ICVD device. One of the Agency's standard procedures is to use the Spent Fuel Attribute Tester (SFAT) to make qualitative attribute tests on fission products of spent fuel assemblies [1]. A great number of the VVER-1000 reactors are in operation in Eastern Europe, especially there are several units in Ukraine. The principal verification problem with those units is connected to the shielded assembly design and sometimes a poor water quality that makes both ICVD and SFAT type verification difficult.

In Ukraine, most of the spent VVER-1000 fuel is shipped away from the facilities back to Russia after typically 5 years of cooling. This means that nowadays and in the near future the spent fuel inventories consist principally of relatively newly used fuel. This is a significant feature of the fuel when a verification method is being figured out for Ukraine. However, there are also older fuel assemblies in the storage ponds and they are getting difficult to verify by the ICVD.

Another problem forms the closed bottles in the storage ponds intended for storage of leaking fuel assemblies. A bottle may be declared as containing a fuel assembly or declared as empty. In both cases a clear verification is needed.

The project to develop a Spent Fuel Attribute Tester (SFAT) for Ukrainian VVER-1000 facilities is running under the Finnish Support Programme to the IAEA safeguards under the Task FIN A 1073 (Annex 1).

The goal of this task is to design and construct a prototype SFAT device suitable for the VVER-1000 NPP facilities in Ukraine. The development work is done in collaboration with the Ukrainian State Authority and the facility operators, so that the safety and operational requirements would be thoroughly fulfilled.

According to the Task Outline, the technical specifications for the VVER-1000 SFAT design, handling, verification procedure, licensing and data evaluation will be drafted. The majority of this work has been reported in the first interim report on the task [2]. Some problems remained unsolved concerning the instrument handling with the refuelling machine and additional measurements for ensuring that the whole system operates in a desirable manner. In addition, it was seen necessary to test a 500 mm^3 cadmium zinc telluride detector and compare it with the scintillation detectors (NaI and BGO), see the revised work plan in Annex 2.

Two complementary measurement campaigns at the Zaporozhye NPP were conducted in June and in September 1999.

The following specific objectives were addressed:

- to test the performance of the cadmium zinc telluride (CZT) detector and compare it with the sodium iodide (NaI) and bismuth germanate (BGO) detectors;
- to test the handling of the SFAT test device with the refuelling machine;
- to test the performance of the SFAT test device in a tight storage lattice including low burnup assemblies with a long cooling time;
- to test the possibility to detect a fuel assembly enclosed in a hermetic bottle.

2 REVIEW OF PREPARATORY WORK

During the first phase of the Task FIN A 1073 [2], the requirements of the different parties, the End User (IAEA, see Annex 3), the National Authority (NRA) and the facility operator (Zaporozhye NPP) were worked out and reported. Also all technical constraints attached to the facility type and the operation practises were worked out and reported.

During the first phase of the task it was proven that the SFAT method could be used for the verification of VVER-1000 assemblies. The tests with the experimental device revealed that a more effective and accurate positioning of the device was necessary. As the operation through the refuelling machine was not yet confirmed, different handling options were introduced and discussed.

Also some questions were left as to the final detector choice. As the optimum measurement geometry is connected with the choice of the detector type, the measurement geometry could not be conclusively specified.

These problems required a complementary measurement campaign to obtain answers to the questions left.

In the first report it was recommended that the verification should take place during period 2 indicated in reference [2]. However, it has come out that this period is reserved for the assembling of the reactor. During this period the access by the refuelling machine to one or two rows in the storage pond closest to the reactor is excluded for technical reasons, and a comprehensive verification cannot be made because of interference with the reactor assembly work.

3 COMPLEMENTARY MEASUREMENTS AT ZAPOROZHYE NPP

The difficulties in positioning of the SFAT during the 1998 experiments [2] lead to the idea to install the device to the refuelling machine. This machine is digitally controlled and may be positioned at any position inside the cooling pool with the precision of ±3 mm horizontally and ±5 mm vertically. This technical option was tested with all detector options.

The complementary measurements were accomplished in two campaigns. The first campaign took place in June 1999 and the second in September 1999. During the first campaign the CZT detector was used whereas in the second campaign the NaI and BGO detectors were tested.

3.1 Detector geometry and hardware

The detectors available for testing were a 500 mm^3 CZT detector, a Ø1 in × 2 in NaI detector, a Ø40 mm × 40 mm NaI detector and a Ø40 mm × 40 mm BGO detector.

The SFAT test device is depicted in Figure 1. Figure 1 illustrates the geometry used with the scintillation detectors. The differences in the geometry used with different detectors are described below. The geometry was specially designed for the measurements in a tight lattice.

For the NaI and BGO detectors the second collimator section length is 1000 mm whereas for the CZT detector a shorter collimator of 300 mm is used as the second section. At the distance of 530 mm from the detector there is an entrance lead collimator with a 10-mm aperture for CZT detector and a 3-mm aperture for the scintillation detectors. At the top of the diaphragm there is a gamma ray filter consisting of 3 mm of lead and 1 mm of copper to suppress the low energy gamma rays. The intermediate collimator in the collimator pipe shields the detector from seeing gamma rays coming from the neighbour assemblies. The aperture in front of the detector entrance is 10 mm. The collimator system limits the direct vision of the detector to cover only one corner of

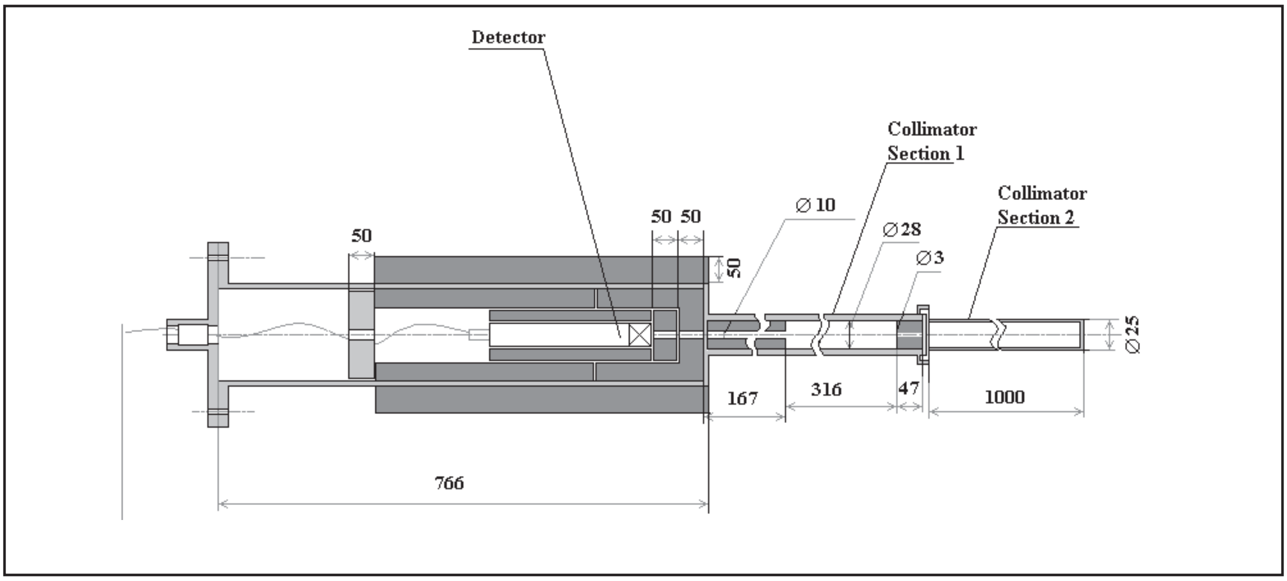

Figure 1. *Schematic drawing of the test SFAT device showing the measurement geometry.*

the assembly on the area, where there are fuel rods.

At the height of the top of the fuel pellets the penumbra seen by the detector in the present geometry extends over a diameter of 37 mm for the CZT detector geometry and 33 mm for the scintillation detector geometry. The ratio of the transmissions of the CZT and scintillation detector geometry was about 13, thus largely compensating for the inferior intrinsic efficiency of the CZT detector. As in the corner there are fuel pins on a circular area of about 46 mm in diameter (see ref. [2]), the device cannot see adjacent fuel assemblies even in a tight storage lattice, if properly positioned. This was clearly shown by the measurements to be described later on.

The lead shield thickness in front of the detector was 50 mm for CZT detector. It was increased into 100 mm for the scintillation detectors, as shown in Figure 1. The shielding was made cylindrically modular so that all empty space could be filled with lead regardless of the diameter of the detector. The total radial lead shielding was 36 mm for the CZT detector, 81 mm for the Ø1 in × 2 in NaI detector and 66 mm for the Ø40 mm × 40 mm detectors (BGO and NaI). Additional steel shielding was used at the top of the scintillation detectors to suppress the radiation coming from above from the contaminated refuelling machine. The top shielding was a 50-mm thick stainless steel ring with the outer diameter 100 mm and the inner diameter 35 mm. This ring was inserted inside the detector unit. The inner hole was for the cable and connectors. Figure 2 shows a photograph of the test device without the additional outer shielding (CZT detector geometry).

The detector with its lead shield was enclosed hermetically into a stainless steel container, where the collimator pipe could be attached.

The SFAT test device is equipped with a 40-m cable, the lower 25 metres of it being enclosed in a waterproof hose, which is hermetically attached in the SFAT test device.

A special adapter imitating the tip of the refuelling machine was manufactured by the Zaporozhye NPP to adapt the SFAT test device in the refuelling machine. A photograph of the adapter is shown in Figure 3.

A schematic drawing of the attachment of SFAT to the refuelling machine is shown in Figure 4.

3.2 Installation and attachment to refuelling machine

A rack was used to introduce the SFAT test device into the pond. The rack is normally used for handling of the fresh fuel. The one used for SFAT installation has a special attachment for visual inspection of the assemblies. This attachment is a piece of hexagonal tube, which fits to the assembly and to the refuelling machine. When the adapter with the SFAT is placed in this attachment, it is rather convenient to attach the adapter to the refuelling machine.

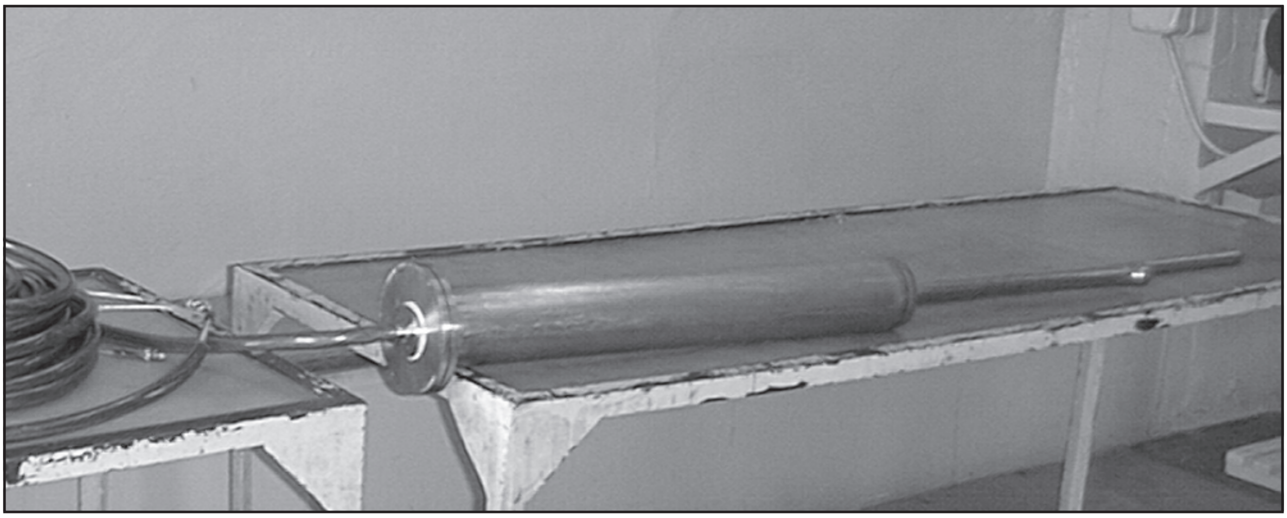

Figure 2. *SFAT test device without additional lead shielding.*

The polar crane of the reactor hall was used to sink the device mounted in the rack into the bottom of the universal socket. Manpower is needed down in the bottom of the universal socket to attach the SFAT device in the refuelling machine. When attached in the refuelling machine the body of the SFAT is inside the mast of the refuelling machine. Only about 300 mm of the collimator pipe extends outside the refuelling machine and the adapter attached to it. See Figures 4 and 5.

Figure 3. *Adapter of the test SFAT device for attachment to the refuelling machine.*

3.3 Measurement system

For the first measurements a portable MCA (Ortec DART) was used to collect the spectra. The MCA was connected to a portable PC running the Sampo 90 measurement control and spectrum analysis software [3]. Parallel measurements were performed with a Canberra InSpector MCA. This device was used also to supply the power and high voltage to the detector [4].

In the second campaign, September 1999, the measurements were performed using only the InSpector hardware and software.

When the Sampo software was used, the measurements were run either by interactively controlling the measurement time through monitoring the spectrum to be collected or by pre-setting a certain level of significance of the target ^{137}Cs peak in the spectrum and letting the program to define the required measurement time. Measurements with the InSpector were done using a fixed live time of 1000 seconds.

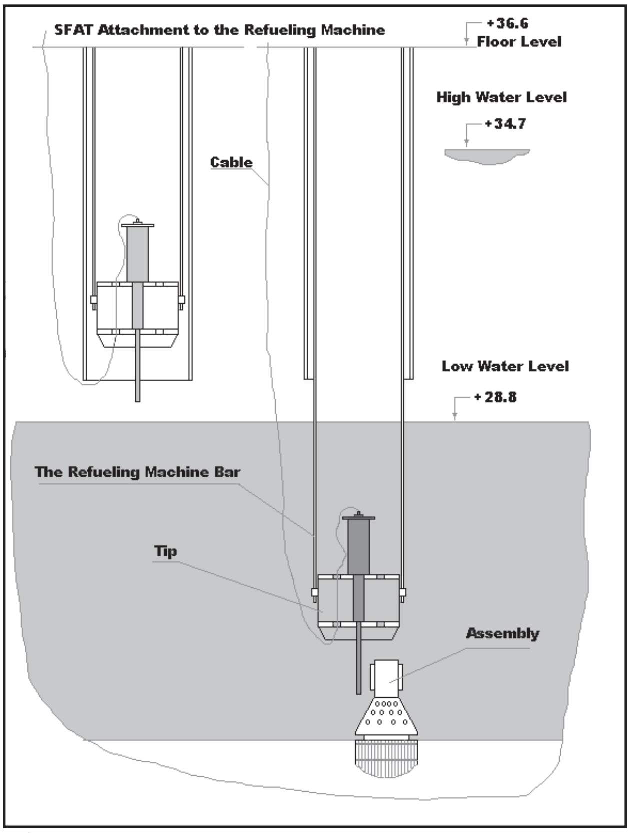

Figure 4. *Release rates of activation and fission products from the near-field into the geosphere (left) and from the geosphere into the biosphere (right) in the SH-sal50 scenario [1, Figure 11-5, p. 137]****.***

3.4 Measurements

3.4.1 Measurements with CZT detector

The first measurement campaign concentrated to testing the CZT detector. This campaign took place at the reactor unit 2. As there is a pond with a tight lattice in units 1 and 2, it was possible to test the SFAT device both in the tight and in the normal storage lattice.

In the first measurement campaign the Ø40 mm × 40 mm NaI detector was also tested. Due to high contamination of the refuelling machine and thin shielding, the background count rate was 57000 cps when attached in the refuelling machine leading to a dead time of about 50 %. The contamination could be attributed mainly to ^{58}Co, ^{60}Co, ^{54}Mn and ^{51}Cr, which are typical compo-

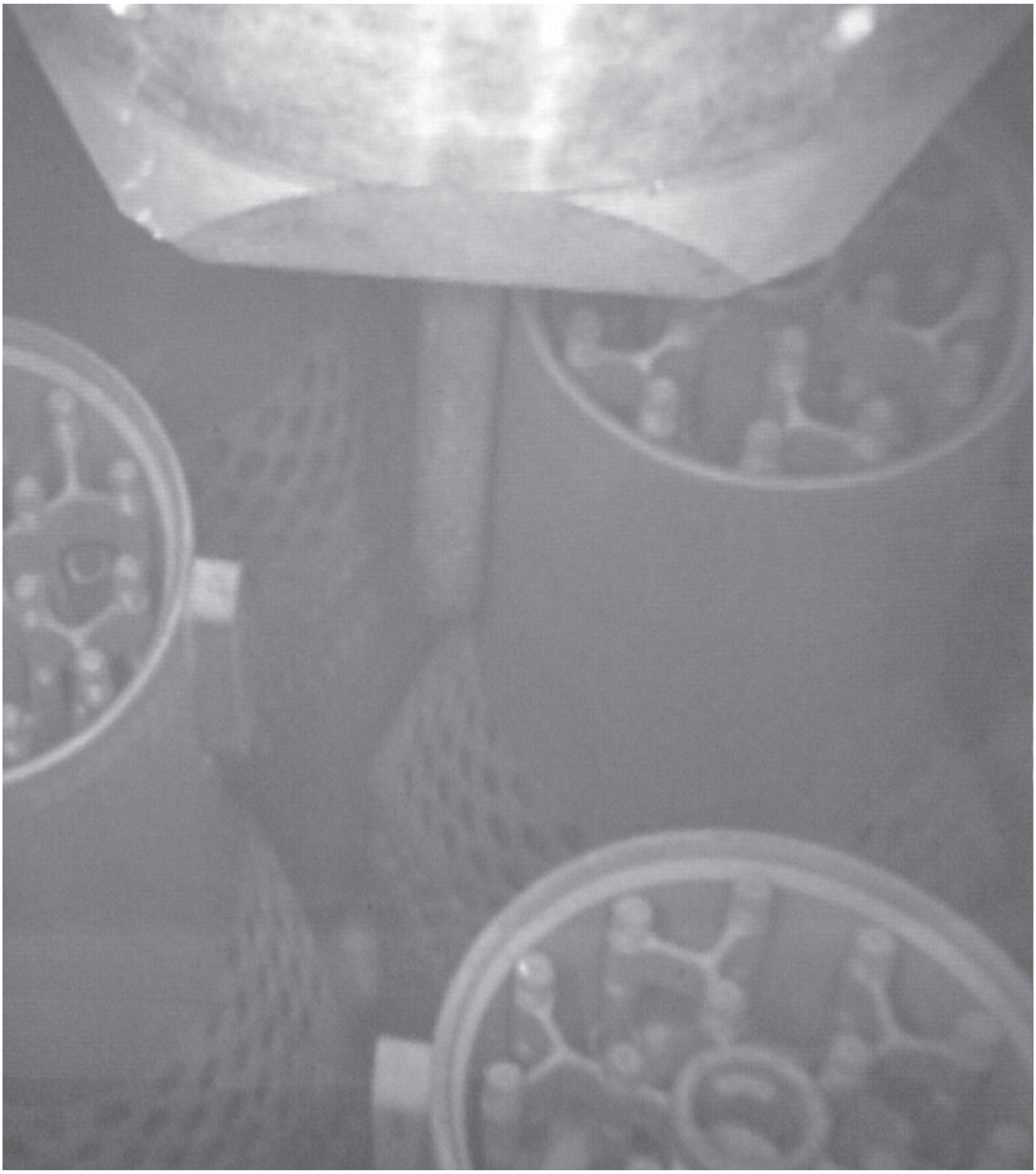

Figure 5. *SFAT test device in the measurement position in a tight lattice.*

Table I. A compilation of the assemblies measured with the CZT detector.

Assembly ID	Average BU MWd/kgU	BU at top MWd/kgU	Fuel cycles	CT months	Residual power kW	Lattice
A0255	12.65	6.03	1	158	0.267	tight
A0304	19.18	7.35	2	96	0.384	tight
N0117	20.03	14.71	2	28	1.307	tight
G2217	29.85	15.05	3	96	0.523	tight
G0332	29.78	22.79	3	134	0.436	tight
V2632	33.92	21.93	3	15	3.873	normal
ED5788	34.92	23.43	3	28	1.967	tight
E0909	43.41	31.55	4	69	0.874	tight
ED5858	46.76	33.64	4	15	4.865	normal

nents of activated products of stainless steel from the assembly's structures precipitated on the surfaces of the refuelling machine. This was experimentally confirmed during the September measurement campaign.

As the shielding could not be added in the field, it was decided to postpone the measurements with the NaI detector. For the same reason the measurements with the BGO detector were considered fruitless, and all measurements were taken using the CZT detector only.

Due to some technical problems, which limited the useful measurement time, the verification of an assembly enclosed in a hermetic bottle could not be tested during this campaign.

A total of 9 assemblies were measured. A compilation of the assemblies measured with the CZT detector is given in Table I. In Table I some additional information on the assemblies is given, e.g. burnup at the top segment and the residual power. This information is discussed later in section 4.2 of this report where the measurement results are evaluated. A summary of the measurements taken with the CZT detector is shown in Table II. The number of spectra collected during this campaign was 24 (including the background spectrum with the NaI detector).

3.4.2 Measurements with NaI and BGO detectors

The main target of the second campaign was to test the scintillation detectors, BGO, NaI Ø40 mm × 40 mm and NaI Ø1 in × 2 in to complement the information for the final decision making about the detectors. The second campaign took place at the reactor unit 4.

The higher efficiency of the scintillation detectors required a longer collimator pipe which required a smaller lower diaphragm of Ø3 mm and a 167 mm long additional protecting collimator, see Figure 1.

During the second campaign, 10 assemblies were measured using 3 detectors. The assemblies had a burnup from about 20 to 48 MWd/kgU. There were no assemblies with lower burnup in the storage pond of reactor unit 4. There is no tight storage lattice of the assemblies in this pond. Measurements of an assembly in a bottle were done. But these measurements show only the fact that spent fuel may be verified in open bottles. As there is lack of free space in the storage pond, non-leaking assemblies have been placed in the bottles for storage, and the bottles were not closed. There were no leaking assemblies stored in closed bottles at unit 4. A list of the assemblies measured with their main features is given in Table III.

Every assembly was measured twice from opposite corners. See Tables IV, V and VI. Assembly E0260 (in the bottle) was measured with the Ø1 in × 2 in NaI detector only above the central axis of the assembly on the first measurement day. The next day the BGO detector was tested, and as the refuelling machine operators were more experienced in the SFAT handling, they managed to position the detector inside the bottle above the assembly shoulder.

The measurements with the Ø40 mm × 40 mm NaI detector were shortened due to lack of time as during the operation the signal cable was broken,

Table II. *Summary of the measurements during the CZT detector measurement campaign.*

Assembly ID	File ID	Measurement time		Dead time	Total count rate	Comment
		Real [s]	Live [s]	[%]	[cps]	
Back-ground	cztb_2	502	497	1.0	441	Attached in the refuelling machine in air, 3-Jun-99
A0255	ass1_h	362	359	0.8	310	On the head of the assembly
A0255	ass1_s	730	718	1.6	836	On the shoulder
E0909	ass2_s	102	96.1	5.8	2810	
E0909	ass2_s2	33	30.8	6.7	2800	Meas. time specified by significance of the Cs-137 peak
G0332	ass3_s	557	540	3.1	1630	
A0304	ass4_s	623	605	3.0	1500	
G2217	ass5_s	544	527	3.1	1640	
ED5788	ass6_s	152	141	7.2	3670	
ED5788	ass6_s2	139	129	7.2	3660	Meas. time specified by significance of the Cs-137 peak
N0117	ass7_s	312	296	5.1	2600	
Back-ground	cztb_3	307	302	1.6	624	As cztb_2, 4-Jun-99
V2632	ass8_s	228	181	20.6	12500	
V2632	ass8_s2	58.0	46.3	20.2	12500	Meas. time specified by significance of the Cs-137 peak
V2632	ass8_s3	181	150	17.1	10600	Opposite corner
V2632	ass8_s4	60.0	49.9	16.8	10600	Position as in previous, meas. time specified by significance of the Cs-137 peak
ED5858	ass9_s1	155	122	21.3	13200	
ED5858	ass9_s2	27.0	21.1	21.9	13200	Meas. time specified by significance of the Cs-137 peak
ED5858	ass9_s3	34	25.7	24.4	15300	Opposite corner, meas. time specified by significance of the Cs-137 peak
ED5858	ass9_s4	610	466	23.6	15300	Position as previous, meas. time fixed
Space	vali_01	402	362	10.0	5390	Space between V2632 and ED5858
Empty	cztb_4	708	658	7.1	3600	Empty position, assemblies in neighbouring positions
Empty	cztb_5	605	593	2.0	782	Empty position, neighbouring positions empty

and it took rather a long time to restore the cable. But this experience showed that special attention should be paid on the cabling of the industrial device.

Other reason was that it was impossible to continue the measurements with the Ø40 mm × 40 mm NaI detector because of a very high background. The background originated from the upper part of the refuelling machine. This detector is longer than the others are, and it was impossible to install the upper shielding lid.

In Tables III, IV, V and VI the measurements performed during the second campaign are summarised.

Table III. *The characteristics of the measured assemblies during the second campaign.*

Assembly ID	Average BU MWd/kgU	BU at Top MWd/kgU	CT months	Comment
A3408	19.92	13.37	120	
A3420	19.92	13.37	120	
A3438	19.92	13.37	120	
E0260	20.07	13.35	87	In the bottle with open lid
G4130	31.61	21.0	111	
G4147	31.61	21.0	111	
G4145	31.61	21.0	111	
E5358	46.40	33.7	38	
E5356	46.51	33.7	38	
E5364	47.84	33.7	38	

Table IV. *Measurement summary for the Ø1 in × 2 in NaI detector.*

Assembly ID	File ID	Live Time	Real Time	Dead Time (%)	Comment
A3408	a31	1000	1007	0.69	Corner
A3408	a32	1000	1007	0.67	Opposite corner
Space	af1	1000	1006.5	0.64	Between A3408 and A3420
A3420	a41	1000	1007	0.66	Corner
A3420	a42	1000	1007	0.71	Opposite corner
Space	af2				Between A3420 and A3438
A3438	a51	1000	1007	0.73	Corner
A3438	a52	1000	1007	0.72	Opposite corner
E0260	a61	1000	1009	0.90	Above the centre with open lid
G4130	a71	1000	1007	0.68	Corner
G4130	a72	1000	1007	0.69	Opposite corner
G4147	a81	1000	1007	0.67	Corner
G4147	a82	1000	1007	0.70	Opposite corner
G4145	a91	1000	1007	0.70	Corner
G4145	a92	1000	1007	0.74	Opposite corner
E5358	a101	1000	1010	0.95	Corner
E5358	a102	1000	1010	0.98	Opposite Corner
E5356	a111	1000	1010	0.97	Corner
E5356	a112	1000	1010	1.02	Opposite corner
Space	af3	1000	1007	0.7	Between E5356 and E5358
E5364	a121	1000	1009	0.92	Corner
E5364	a122	1000	1010	0.99	Opposite Corner
Background	a0	503	511	1.53	In the socket without shielding
Background	a1	522	527	1.03	In the refuelling machine above the water

Table V. Measurement summary for the Ø40 mm × 40 mm BGO detector.

Assembly ID	File ID	Live Time	Real Time	Dead Time (%)	Comment
A3408	b11	1000	1049	4.67	Corner
A3408	b12	1000	1049	4.66	Opposite corner
Space	bf1	1000	1049	4.63	Between A3408 and A3420
A3420	b21	1000	1049	4.68	Corner
A3420	b22	1000	1049	4.70	Opposite corner
Space	bf2	1000	1049	4.65	Between A3420 and A3438
A3438	b31	1000	1049	4.70	Corner
A3438	b32	1000	1050	4.72	Opposite corner
E0260	b41	1000	1049	4.70	Above the centre with open lid
E0260	b51	1000	1049	4.70	Above the corner with open lid
E0260	b52	1000	1050	4.75	Above the corner with open lid
G4130	b61	1000	1050	4.78	Corner
G4130	b62	1000	1050	4.81	Opposite corner
G4147	b71	1000	1051	4.82	Corner
G4147	b72	1000	1051	4.84	Opposite corner
G4145	b81	1000	1051	4.81	Corner
G4145	b82	1000	1051	4.85	Opposite corner
E5358	b91	1000	1053	5.06	Corner
E5358	b92	1000	1054	5.12	Opposite corner
E5356	b101	1000	1054	5.13	Corner
E5356	b102	1000	1055	5.26	Opposite corner
Space	bf3	1000	1050	4.82	Between E5356 and E5358
E5364	b111	1000	1057	5.36	Corner
E5364	b112	1000	1055	5.21	Opposite corner
Background	t301	1000	1052	4.99	In the hall in stainless box without lead
Background	t302	1000	1015	1.47	In the hall in inner shielding
Background	t303	1000	1037	3.54	In the hall without shielding

Table VI. Measurement summary for the Ø40 mm × 40 mm NaI detector.

Assembly ID	File ID	Live Time	Real Time	Dead Time (%)	Comment
A3408	c11	1000	1156	13.47	Corner
A3408	c12	1000	1159	13.71	Opposite corner
E0260	c41	1000	1159	13.69	Above the corner with open lid
G4145	c71	1000	1166	14.24	Corner
E5356	c91	1000	1173	14.78	Corner
Background	b201	1000	1111	10.01	In stainless steel box without lead in socket
Background	b202	1000	1082	7.59	In the socket in inner shielding
Background	b203	307	314	2.34	In the hall without any shielding
Background	b204	1000	1012	1.20	In the hall in shielding
Background	b205	1000	1038	3.66	In stainless box without lead in the hall
Background	cf0	1000	1160	13.78	In the refuelling machine in universal socket

4 EVALUATION OF MEASUREMENT RESULTS

4.1 System operation

The operation of the SFAT test device was rather smooth. The device could be positioned accurately, and the position could be verified in two ways, through the monitor of the refuelling machine and by the digital control system of the machine. In practice the machine is automatically positioned above the selected assembly, see Figure 4. During the positioning for the measurement of the first assembly the necessary horizontal and vertical displacements of the refuelling machine are defined and further positionings are done quickly using the digital positioning system. The TV camera is used only for verification of the proper position of the collimator tip.

The vertical level of the tip of the collimator was at the corner, where the conical part of the upper structure of the assembly ends and the cylindrical top part starts (Figure 4). From that level the distance to the top of the fuel pellets is approximately 475 mm, see also Figure 17.

The idea of attachment of the SFAT device to the refuelling machine appeared to be fruitful as it makes possible the best use of the underwater TV camera of the refuelling machine. The mast of the TV is specially designed for rotating around the mast of the refuelling machine. So it is possible to verify the position of the collimator tip from two perpendicular directions ensuring the correct positioning of the device with respect to the assembly.

Special attention had to be paid to protect the cable from being caught by the video mast during the positioning of the device. During the handling of the SFAT test device one person from the NPP staff was engaged in watching the cable. During the second measurement campaign there was an accident where the cable was broken, as it was not controlled for a short time. For the industrial SFAT device a technical solution must be devised to prevent the possibility of any such accidents.

4.2 Measurements with CZT detector

A spectrum measured with 141 seconds of live time from assembly ED5788 (average burnup 34.92 MWd/kg, cooling time 28 months) is given as an example in Figure 6. A detail of the spectrum showing the peaks of ^{137}Cs and ^{134}Cs is given in Figure 7. Another spectrum taken from a short time cooled assembly ED5858 (average burnup 46.76 MWd/kgU, cooling time 15 months) is shown in Figure 8. A detail of the spectrum is shown in Figure 9. The additional peak in the interval of the most prominent peaks of ^{137}Cs and ^{134}Cs is due to ^{95}Zr (757 keV) and its daughter nuclide ^{95}Nb (766 keV). Although ^{95}Zr is a fission product, the majority of it is produced by activation of the zirconium structures of the fuel assembly and therefore it cannot be considered as a fingerprint of fission products.

A list of the peak intensities analysed from the spectra is given in Table VII. The error limits given correspond to the standard deviation obtained from the fit with Sampo 90. In Figure 10a the ^{137}Cs peak intensities vs. average burnup are plotted with the error bars shown in Table VII. Some correlation is observed, but the scattering of the measured points does not permit to estimate any reliable correlation line. In addition, the signal disappears for average burnups below 20 MWd/kg, and does not seem to cross the origin. Sensitivity and signal-to-background ratio must be improved before a reliable verification can be obtained for average burnups below 20 MWd/kg.

Table VII shows also, that the measurement

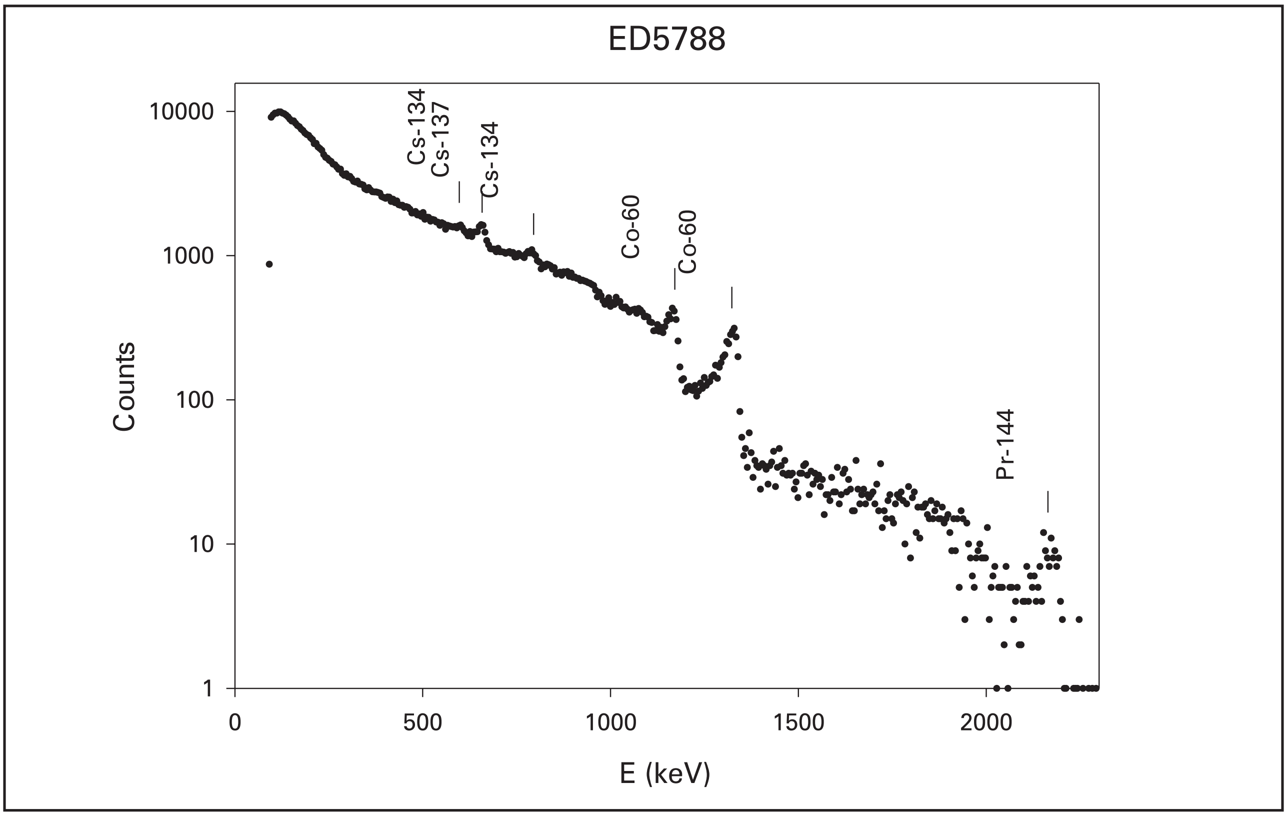

Figure 6. *A spectrum measured with the SFAT test device using the CZT detector. Assembly ED5788 with the burnup 34.92 MWd/kgU and cooling time 28 months. The measurement live time was 141 seconds.*

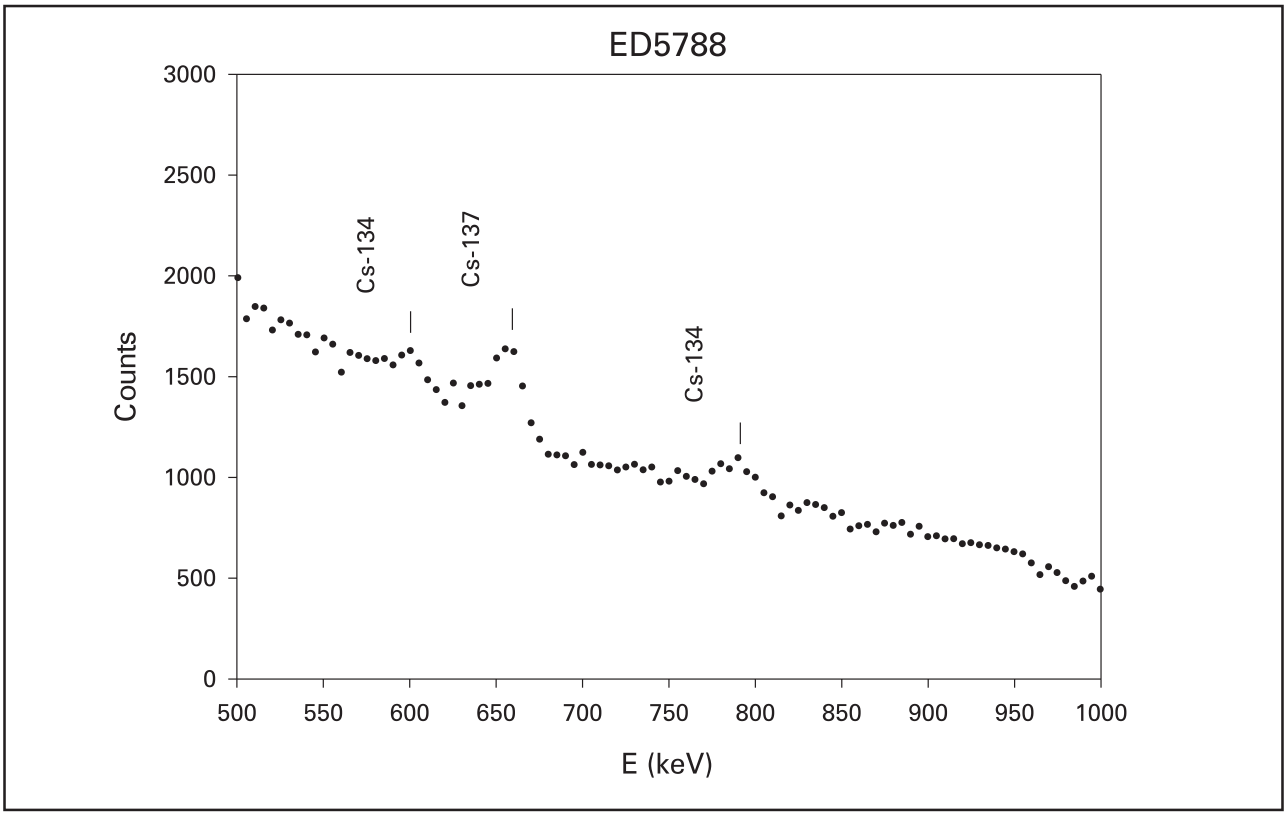

Figure 7. *A detail of figure 6 showing the ^{134}Cs and ^{137}Cs peaks.*

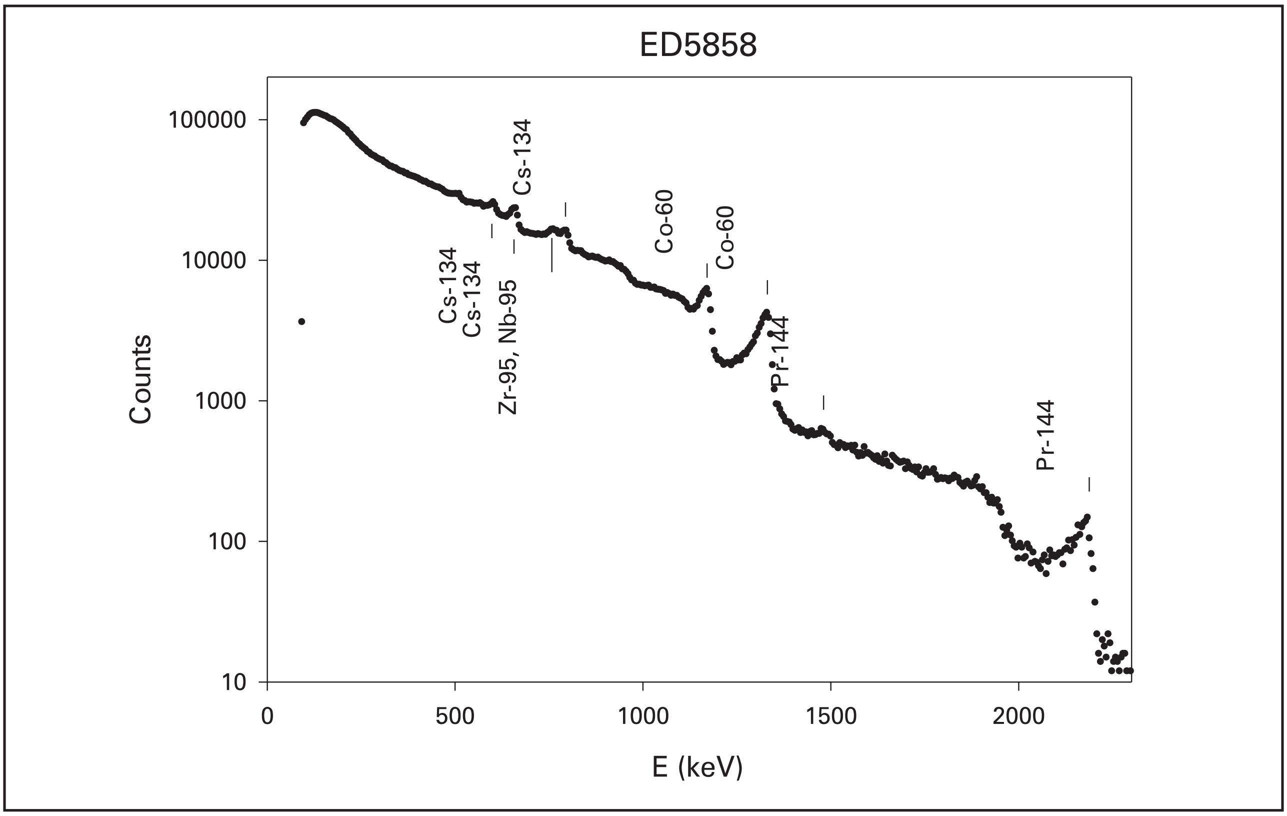

Figure 8. *A spectrum of a short time cooled assembly. Assembly ED5858 with the burnup 46.76 MWd/kgU and cooling time 15 months. The measurement live time was 466 seconds.*

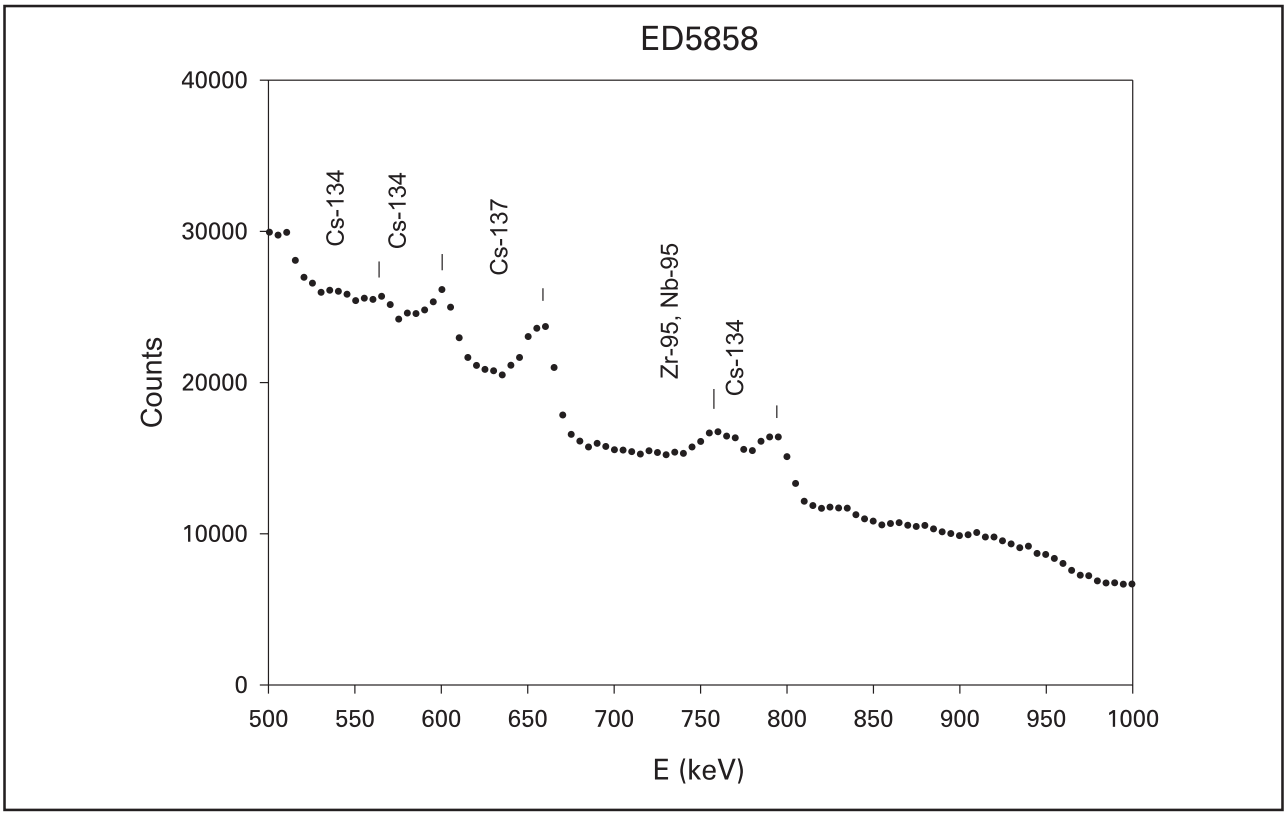

Figure 9. *A detail of figure 8 showing the ^{134}Cs, ^{137}Cs, ^{95}Zr and ^{95}Nb peaks.*

Table VII. *The intensities and of the detected ^{137}Cs peaks at the measurements with the CZT detector. The values are reduced to the date of discharge. The errors given correspond to the error indicated by the peak fitting with Sampo 90.*

Assembly ID	Average BU [MWd/ kgU]	BU at top [MWd/ kgU]	CT months	Residual power [kW]	Live time [s]	Total count rate [cps]	Cs-137	
							Peak [cps]	Error [cps]
A0255	12.65	6.03	158	0.267	718	836	0.00	—
A0304	19.18	7.35	96	0.384	604	1500	0.43	0.29
N0117	20.03	14.71	28	1.307	296	2600	6.54	0.59
G2217	29.85	15.05	96	0.523	527	1640	2.10	0.28
G0332	29.78	22.79	134	0.436	540	1630	7.82	0.36
V2632	33.92	21.93	15	3.873	181	12500	32.78	1.80
V2632	33.92	21.93	15	3.873	463	12500	40.17	3.42
V2632	33.92	21.93	15	3.873	150	10600	42.67	2.35
V2632	33.92	21.93	15	3.873	499	10600	46.26	4.21
ED5788	34.92	23.43	28	1.967	141	3670	19.96	0.98
ED5788	34.92	23.43	28	1.967	129	3660	18.60	1.15
E0909	43.41	31.55	69	0.874	96.1	2810	25.26	1.16
E0909	43.41	31.55	69	0.874	30.8	2800	25.21	2.17
ED5858	46.76	33.64	15	4.865	122	13200	67.99	3.20
ED5858	46.76	33.64	15	4.865	211	13200	78.57	4.80
ED5858	46.76	33.64	15	4.865	25,7	15300	84.66	5.41
ED5858	46.76	33.64	15	4.865	466	15300	83.93	1.68

over an empty position and over the space between two highly irradiated assemblies gives zero value for the ^{137}Cs peak.

Figure 10b shows the ^{137}Cs peak intensities vs. the burnup of the top part of the assemblies. The operator calculates the burnup profile in 10 vertical segments, and these values correspond to the top segment. At least two of the low ^{137}Cs peak values (A0304 and G2217) are explained with the low burnup of the top part of the assembly due to a partially inserted control or absorbing rod during irradiation.

The points in Figure 10 fall clearly into two data sets. The distribution into two different data sets can be attributed to differences in the irradiation history. A regression line has been drawn through the measurement points of the assemblies in the tight lattice. The outlyers, V2632 and ED5858 were located in the normal lattice and had the shortest cooling time.

The straight lines in Figure 10 represent a linear fit to the data points when the outlyers are excluded. The regression analysis has been performed using SigmaPlot software [5]. The experimental data are better explained with the top part burnup than with the average burnup. The correlation coefficient of the fit to the average burnup is 0.905 whereas the coefficient for the fit to the top part burnup is 0.934.

Two assemblies, V2632 and ED5858, were measured at two opposite corners with respect to their central axis. Both measurements were repeated. Also the measurements of the assemblies ED5788 and E0909 were repeated. The scattering of the repeated measurements is indicated in Figure 10. One can conclude that the repeatability of individual measurements is fairly good. Only in the measurement at one corner of assembly V2632 the scattering exceeds the indicated error limits.

Figure 11 shows the correlation between the average burnup and the burnup of the top part. It is obvious, that for high burnups the correlation is very high, whereas for low burnups some points clearly fall out of the line (A0304 and G2217). This is confirmed from the irradiation history of these assemblies.

Figure 12 depicts the correlation between the total count rate and the declared residual power. The correlation coefficient to the linear fit is 0.977, and the curve crosses the origin within the statis-

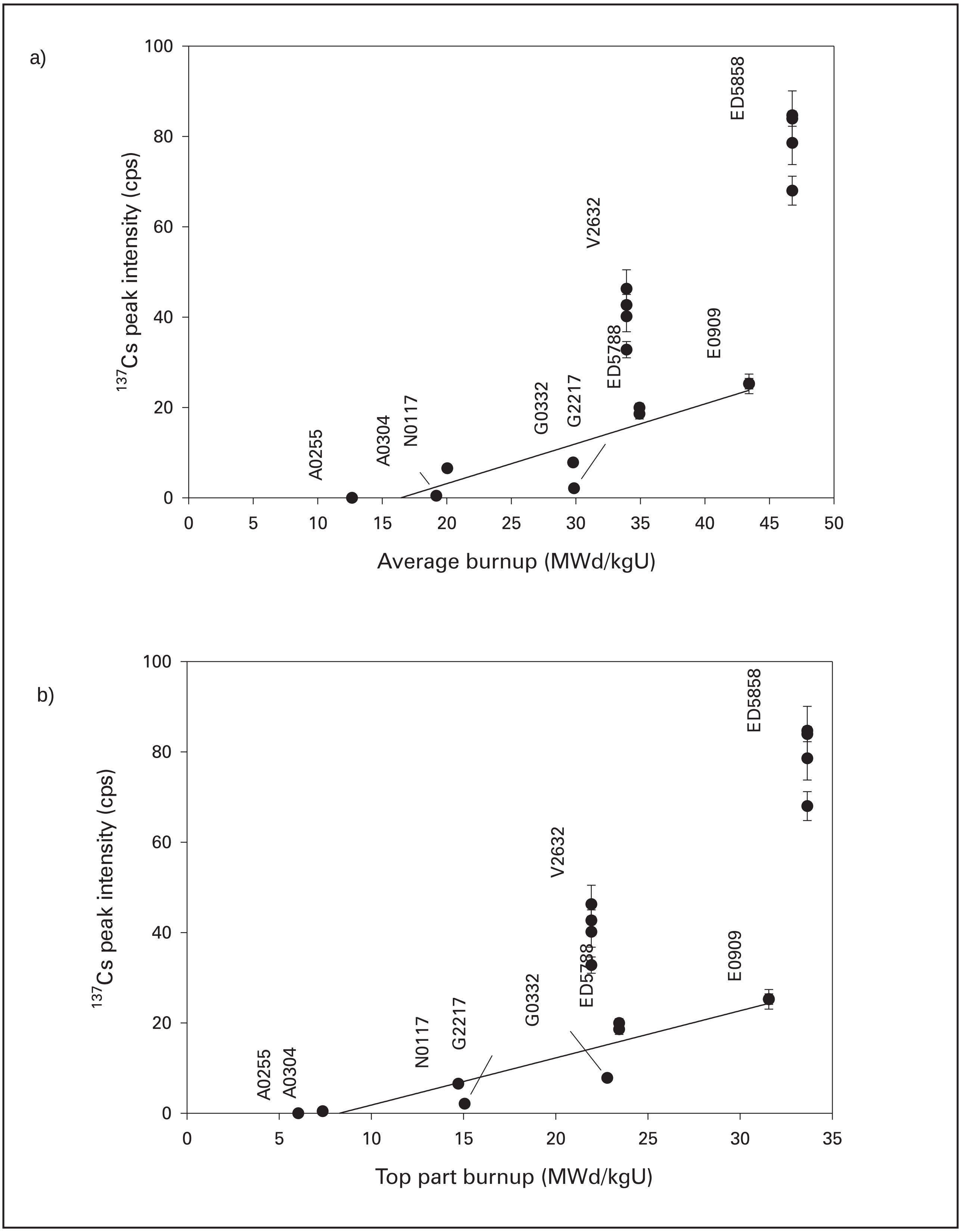

Figure 10. *a) The ^{137}Cs peak intensities vs. average burnup as measured with the CZT detector. b) The measured ^{137}Cs peak intensities vs. top part burnup.*

tical accuracy. The total count rate rather well correlates with the residual power, which information is also available. So this parameter, as well as the burnup of the top part, may be used for coarse preliminary measurement time estimation.

Although it would be desirable to get a good

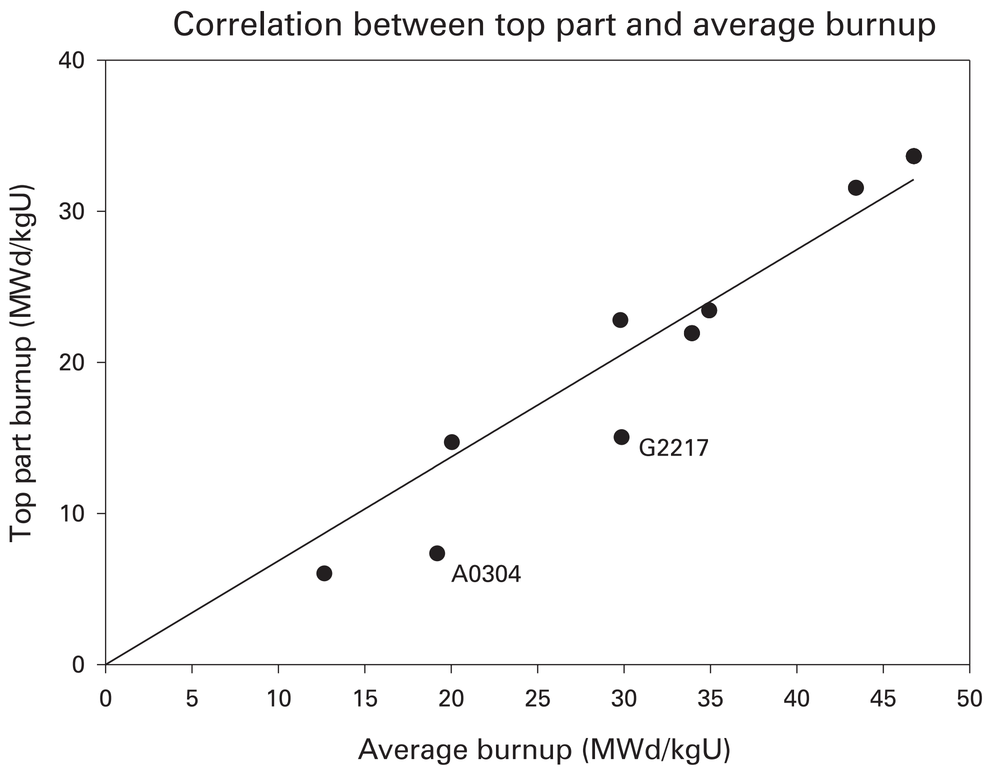

Figure 11. *Correlation between the top part and average burnup as measured with the CZT detector.*

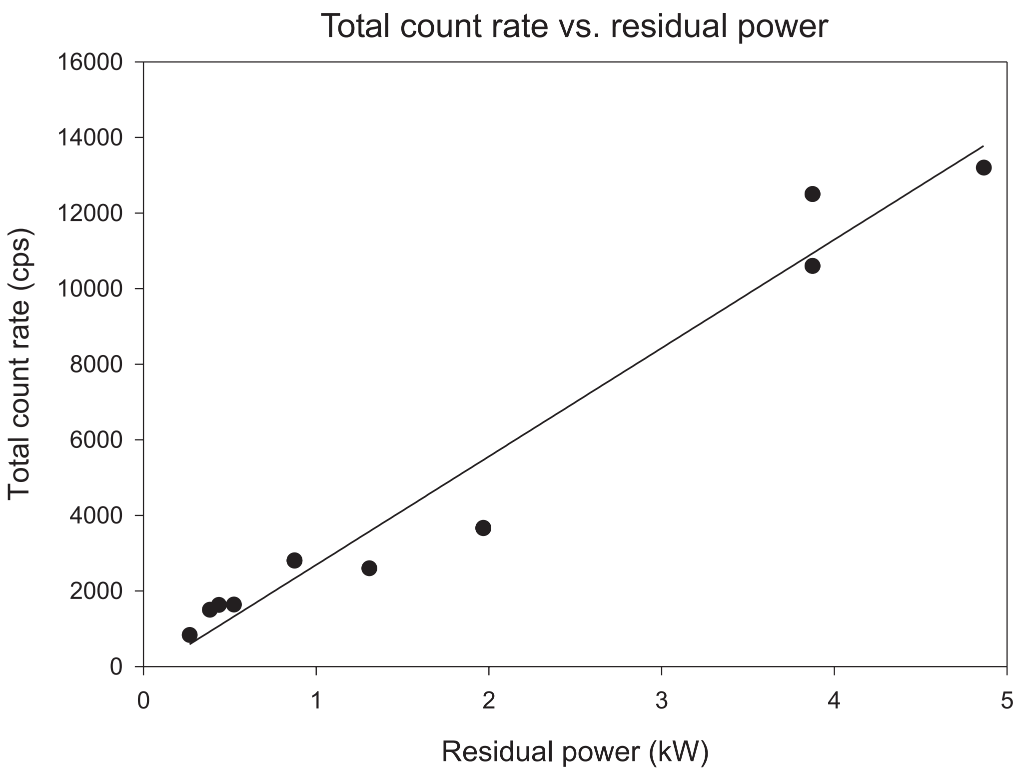

Figure 12. *The correlation between the total count rate and the residual power.*

Table VIII. A compilation of the evaluation of the ^{137}Cs peaks measured with the Ø1 in × 2 in NaI detector. Zero value signifies that the peak was not detected.

Assembly ID	BU [MWd/kgU]	Data Evaluation for ^{137}Cs				Comment
		InSpector		SAMPO		
		Area cps	Error %	Area cps	Error %	
A3408	19.92	0.73	51.5	0.20	81.2	Corner
A3408	19.92	0.96	32	0	—	Opposite corner
Space	—	1.12	33	0.38	35. 8	Between A3408 and A3420
A3420	19.92	1.38	26	0.40	49.9	Corner
A3420	19.92	1.26	32	0.42	29.1	Opposite corner
Space	—	0.53	72	0.32	53.6	Between A3420 and A3438
A3438	19.92	1.22	33	0	—	Corner
A3438	19.92	1.01	39	0.66	28.4	Opposite corner
E0260	20.07	0		0	—	Above centre with open lid
G4130	31.61	1.50	24	0.38	20.1	Corner
G4130	31.61	2.20	17.3	1.19	20.4	Opposite corner
G4147	31.61	1.15	28.8	1.50	22.7	Corner
G4147	31.61	1.85	21.8	1.19	12.5	Opposite corner
G4145	31.61	1.45	26	2.19	23.5	Corner
G4145	31.61	1.82	22	1.21	12.6	Opposite corner
E5358	46.40	3.01	12.3	4.51	11.1	Corner
E5358	46.40	1.79	22	2.06	12.1	Opposite corner
E5356	46.51	1.44	30	1.27	14.6	Corner
E5356	46.51	2.36	16.2	2.01	10.3	Opposite corner
Space	—	0.58	58	0	—	Between E5356 and E5358
E5364	47.84	1.71	22.7	5.64	27.8	Corner
E5364	47.84	2.06	22.3	2.32	8.0	Opposite corner

linear correlation between the burnup and the ^{137}Cs peak intensity, it must be reminded that the target of the SFAT method is only to obtain an unambiguous verification of a spent fuel assembly by detecting the ^{137}Cs peak.

4.3 Measurements with NaI(Tl) Ø 1" × 2" detector

A compilation of the measurements taken is shown in Table VIII. A total of 10 assemblies were measured. The number of the spectra collected was 24.

The spectra were analysed independently by two software instruments, by the InSpector software and by Sampo.

The results obtained by both methods are rather close, especially for high burnups. The discrepancy lies in the low burnup region. As it is seen, some low burnup assemblies were verified only during one of two measurements if using SAMPO and for all cases using InSpector. At the same time InSpector detected ^{137}Cs peaks in the background in all cases, and SAMPO only in one. All these discrepancies show that some special software should be developed for industrial prototype of the instrument if a NaI detector is chosen.

The results of the InSpector data evaluation are plotted in Figure 14. The regression coefficient of the linear fit to the data points is 0.705 reflecting the large scattering of the data. The regression line crosses zero burnup value at 0.56 cps, which is exactly two standard deviations above zero. This indicates some background radiation, which adds to the ^{137}Cs peak measured from the assemblies. The standard error of the estimate is

0.41 cps indicating that only ^{137}Cs peak values higher than about 1.2 cps are strongly significant, over 3 times the standard error above zero. In conclusion, even an assembly with the burnup of about 20 MWd/kgU (top part burnup about 14 MWd/kgU) may remain unverified for a measurement time of 1000 seconds.

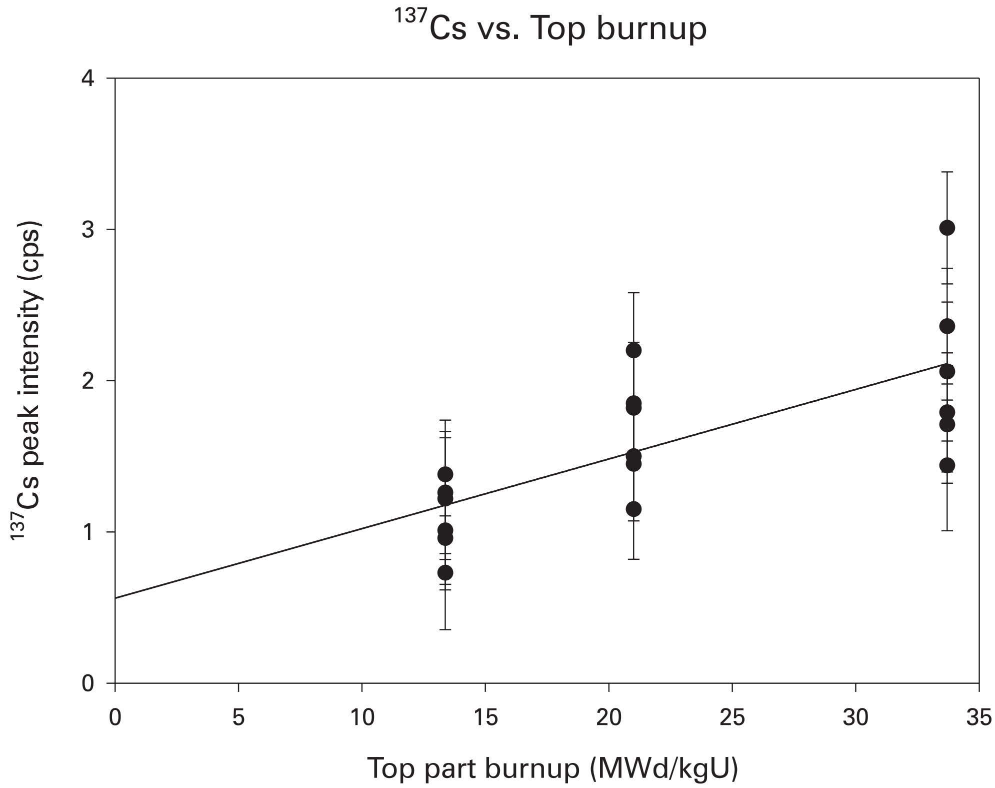

Figure 13. *The ^{137}Cs peak intensities vs. top part burnup as measured with the Ø1 in x 2 in NaI detector.*

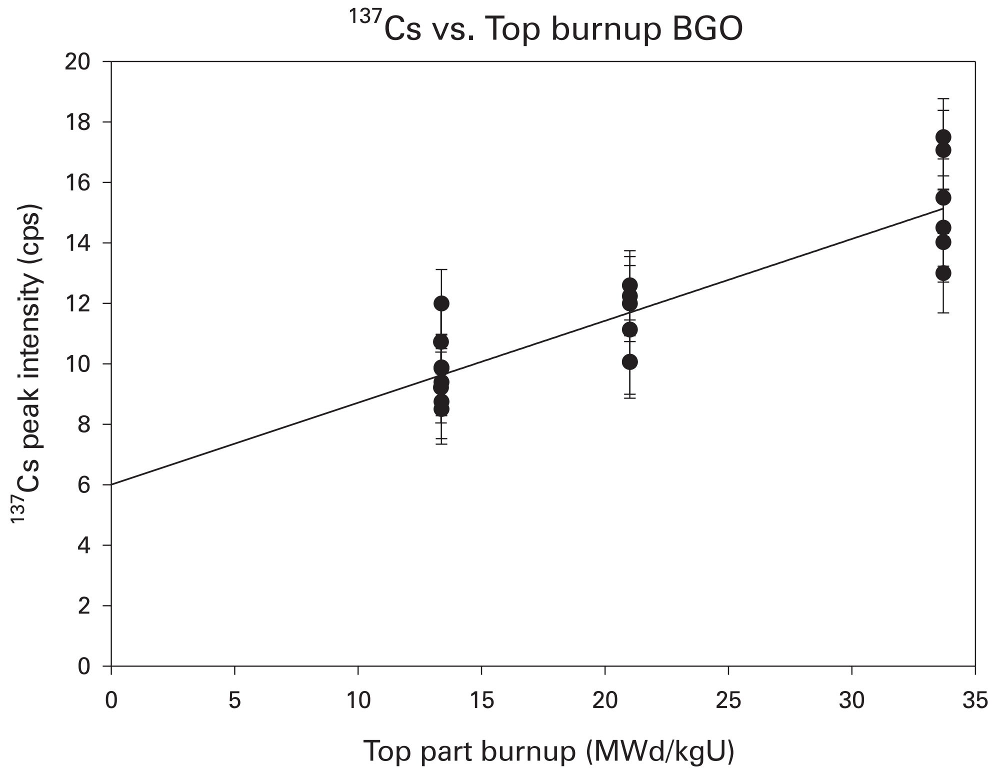

Figure 14. *The ^{137}Cs peak intensities vs. burnup as measured with the Ø40 mm x 40 mm BGO detector.*

Table IX. The intensities of the detected peaks as reduced to the discharge date.

Assembly ID	BU [MWd/kgU]	Data Evaluation for ^{137}Cs				Comment
		InSpector		SAMPO		
		Area cps	Error %	Area cps	Error %	
A3408	19.92	9.88	11.1	6.26	11.4	Corner
A3408	19.92	9.85	11.2	7.69	9.8	Opposite corner
Back-ground	0151	6.89	14.8	5.90	18.7	Between A3408 and A3420
A3420	19.92	8.75	14.0	6.43	12.4	Corner
A3420	19.92	11.99	9.4	7.24	11.8	Opposite corner
Back-ground	—	6.81	14.5	7.39	11.7	Between A3420 and A3438
A3438	19.92	8.50	13.7	6.53	11.1	Corner
A3438	19.92	9.39	11.8	6.65	7.1	Opposite corner
E0260	20.07	7.57	14.6	3.41	32.2	Above centre with open lid
E0260	20.07	9.22	12.7	7.89	10.0	Above corner with open lid
E0260	20.07	10.72	11.4	6.51	13.6	Above corner with open lid
G4130	31.61	10.07	10.7	8.24	7.1	Corner
G4130	31.61	11.13	11.1	9.51	9.1	Opposite corner
G4147	31.61	12.59	9.1	8.45	7.6	Corner
G4147	31.61	12.24	10.7	8.32	8.2	Opposite corner
G4145	31.61	10.05	11.9	7.81	8.0	Corner
G4145	31.61	11.99	10.5	8.06	9.4	Opposite corner
E5358	46.40	13.00	10.1	9.89	9.2	Corner
E5358	46.40	15.49	8.3	13.54	5.3	Opposite corner
E5356	46.51	14.02	9.4	10.14	7.0	Corner
E5356	46.51	17.06	7.7	12.10	7.2	Opposite corner
Back-ground	—	9.49	12.2	7.82	7.8	Between E5356 and E5358
E5364	47.84	17.49	7.3	24.46	5.2	Corner
E5364	47.84	14.50	8.8	8.26	10.1	Opposite corner

4.4 Measurements with BGO detector

A compilation of the measurements taken is shown in Table IX. As for NaI detector the spectra were analysed independently by two software instruments, by the InSpector software and by Sampo.

The results obtained by both analysis methods are rather close, especially for high burnups. In difference with NaI data there is a rather strong correlation between two estimation methods the high values obtained with one method are high with the other, too.

Figure 14 displays the results of the InSpector data evaluation. The regression coefficient of the linear fit to the data points is 0.876 indicating a better linear correlation than for the NaI detector. The regression line crosses zero burnup value at 6.0 cps (standard error 0.8 cps) indicating high background radiation. The standard error of the estimate is 1.3 cps indicating that only ^{137}Cs peak values higher than about 10 cps are strongly significant, over 3 times the standard error above the zero-crossing value. In conclusion, an unambiguous positive verification can be obtained only for an assembly with the burnup of about 30 MWd/kgU (top part burnup about 20 MWd/kgU) for a measurement time of 1000 seconds.

4.5 Measurements with NaI(Tl) Ø 40 × 40 mm detector

The measurements with the Ø40 mm × 40 mm NaI detector discovered a background source. The measurements were taken without the steel shield above the detector for technical reasons. The background of the assembled measurement system in the dry universal socket (file cf0 in Table VI) is higher than the signal from low burnup assemblies (e.g. file c11 in Table VI).

During the measurements the detector unit is under water, which forms additional shielding against the radiation coming from above from the contaminated refuelling machine structures. Figure 15 shows the detector background spectrum inside the refuelling machine in the dry universal socket and a spectrum measured from a low burnup assembly. The background measured in the universal socket is seen to be slightly higher in intensity than the total signal (including local background) from the low burnup assembly. This clearly shows that the background originates mainly from the upper part, most probably from the assembly attachment of the refuelling machine.

4.6 Comparison of detectors

Figure 16 displays on the same energy scale spectra taken by all three different detector types. The spectrum measured with the CZT detector has been taken from assembly ED5788 (BU 46.76 MWd/kgU, CT 15 months) and the scintillation detector spectra have been taken from assembly E5364 (BU 47.84 MWd/kgU, CT 28 months).

For the CZT spectrum the cooling time was so short that a peak around 760 keV (^{95}Zr 757 keV, ^{95}Nb 766 keV) was visible. See also Figure 9. This peak interferes with the 796 keV peak of ^{134}Cs in such an extent that with low-resolution detectors (NaI and BGO) it is impossible to distinguish whether the 795 keV peak contains contamination of ^{95}Zr and ^{95}Nb. Even with a very short half-life

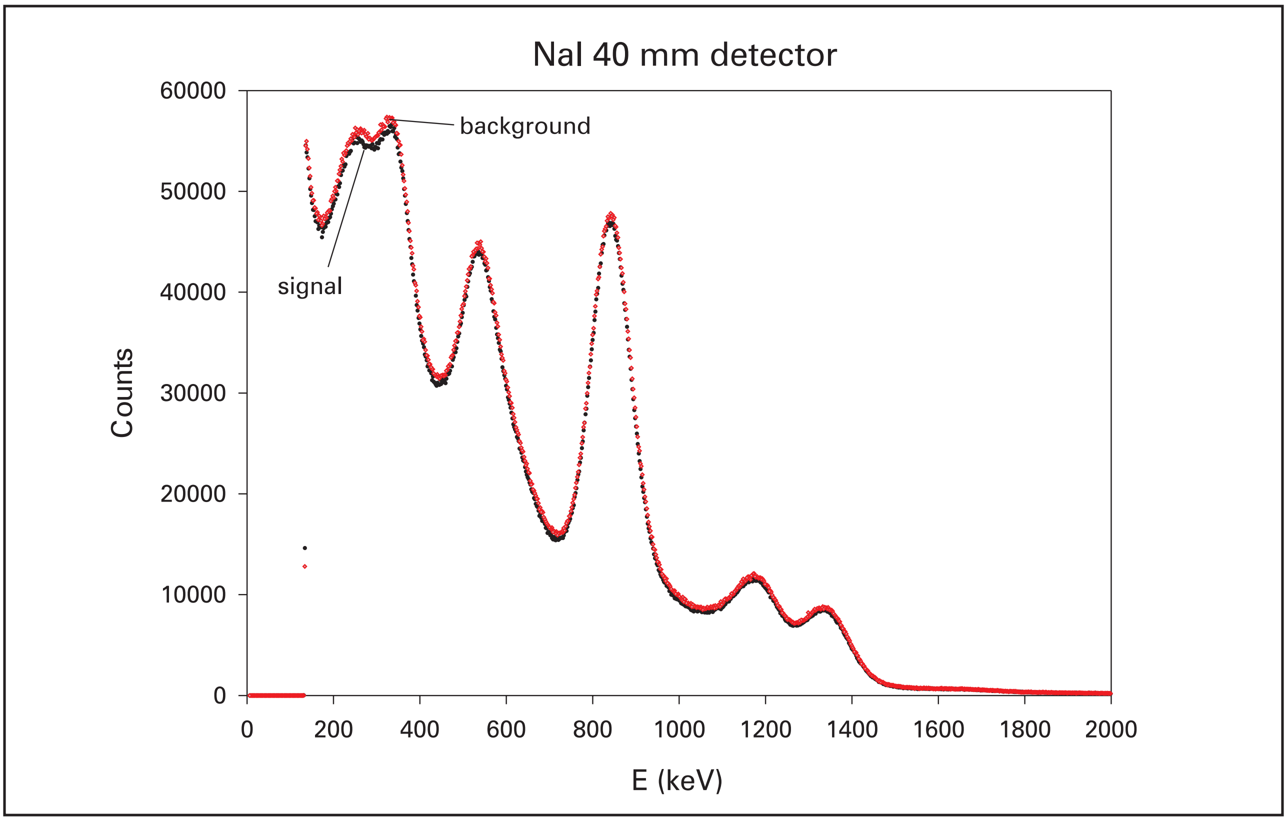

Figure 15. *The background and spectrum as measured with the Ø40 mm x 40 mm NaI detector. For more explanation, see text.*

(64 days) the amount of zirconium in the fuel assemblies is so high that it is clearly visible after 15 months. In assemblies having cooled for 28 months this peak is no more visible, see Figure 7. More severe is the interference between the 605 keV peak of ^{134}Cs and the 662 keV peak of ^{137}Cs. In Figure 16 the CZT detector clearly distinguishes these two peaks, whereas these peaks are merged into one peak in both the NaI and the BGO spectra. This may lead into erroneous interpretation of this peak coming from ^{137}Cs independently of whether its peak is present or not. As a matter of fact the peak analysis shown in Tables VIII and IX interprets this doublet as one peak, which leads necessarily to an erroneous cooling time correction. This may be one reason for the observed high scattering of the peak intensities measured from the assemblies with the same burnup.

Although ^{134}Cs is a fission product as well as ^{137}Cs, according to the SFAT procedure [1] the verification must be based on the detection of ^{137}Cs or alternatively ^{144}Pr for the fuel cooled for less than about four years. Therefore the verification based on unambiguous detection of the ^{137}Cs peak is of primary importance. In the case of VVER-1000 fuel it looks that this could be achieved only using a CZT detector.

In the case of a low resolution detector, the overlapping peaks could be separated by unfolding the responses of individual gamma peaks. This would require sophisticated mathematical technique with sufficient prior information on the expected nuclides and on the detector response to each gamma peak and to the background radiation. Accordingly a high resolution detector should be preferred because it allows the use of any commercially available gamma spectrometric software for the analysis of the spectra.

Different factors affecting the choice of the optimal detector are considered in Table X. The figures given for each detector and the weighting of each property according to its importance are subjective, but they illustrate, which properties have been considered in the detector choice. As discussed above, the highest importance has been given to the resolution as it is considered as the crucial parameter.

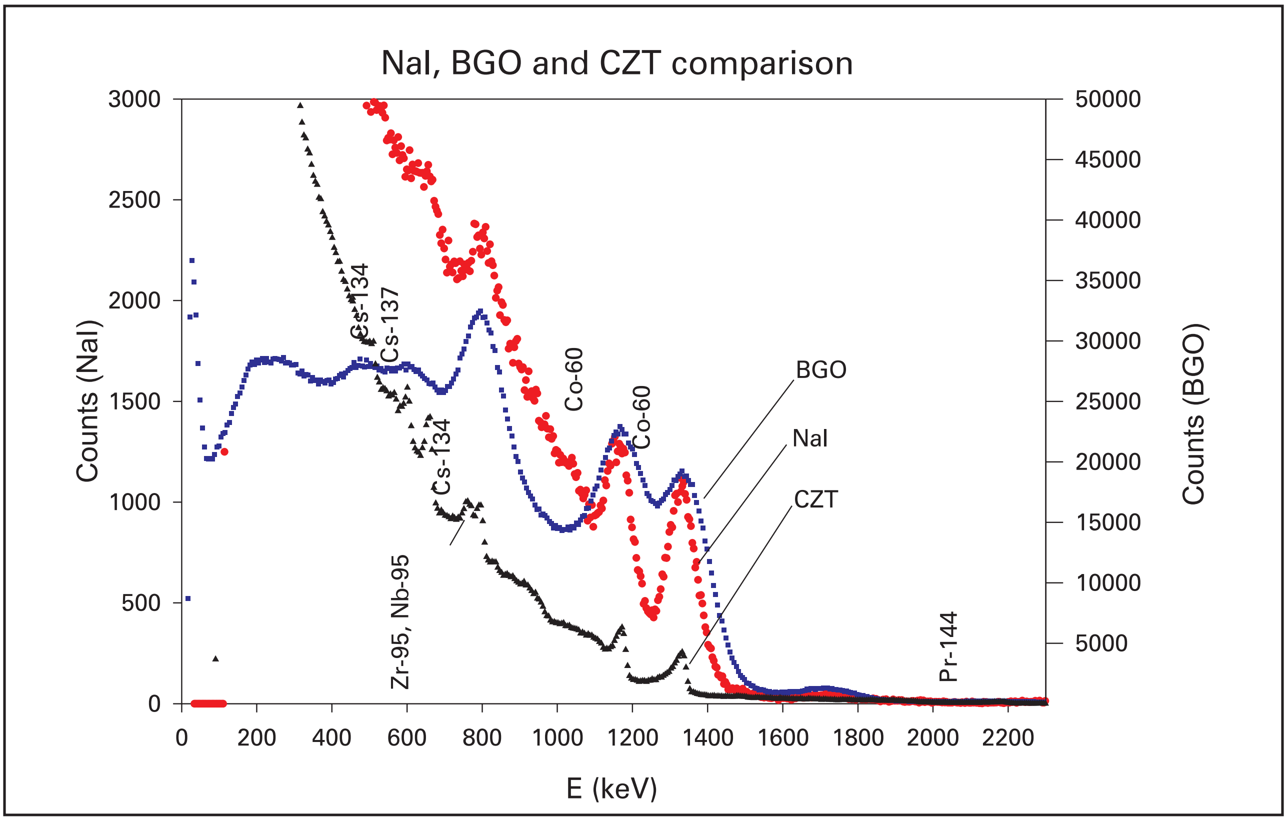

Figure 16. *Comparison of spectra measured with different detectors.*

Table X. *A table for the evaluation of the "figure of merit" of alternative detectors.*

Property	Importance	CZT		NaI		BGO	
		Unweighted	Weighted	Unweighted	Weighted	Unweighted	Weighted
Resolution	10	5	50	2	20	1	10
Efficiency	3	1	3	3	9	5	15
Physical size	5	5	25	2	10	2	10
Temperature stability	5	5	25	3	15	3	15
Peak-to-Compton	3	2	6	4	12	5	15
Total weighted figure of merit			**109**		**66**		**65**

4.7 Measurement analysis software

The 1998 measurements resulted in report [2] containing the technical specification. Special chapter of this report was devoted to the software. The 1999 measurements showed that this question is very significant with the scintillation detectors as comparative usage of two possible procedures showed some difference in estimated results. The fundamental reason for these differences is the low resolution of the scintillator detectors making the peak area determination very sensitive to different models for the peak form and the background available in the software. On the other hand it depends on the skill and carefulness of the software operator in the energy and peak form calibration.

This problem is less important for the CZT detector, because its better resolution gives a clearly resolved ^{137}Cs peak. From the CZT spectra the peak area can be determined using any commercially available gamma spectrum analysis software. All gamma spectrum software accepted for the use in the IAEA safeguards measurements e.g. the SPEC or WINSPEC attached to the MMCA hardware is compatible with the SFAT test device equipped with a CZT detector.

The use of the scanning mode of the SFAT device appeared to be impossible, as all assemblies are oriented with their attachment studs directing towards the only possible line for scanning. These studs are visible in Figures 4 and 5 at the top part of the assemblies. The space occupied by these studs prevents the positioning of the device above the corner in the direction of the stud. Therefore special software to support the scanning mode will not be needed.

4.8 Conclusions from measurements

The following conclusions can be drawn based on the measurements so far conducted in the task:

- Unambiguous verification of the assemblies above 20 MWd/kg average burnup (or 14 MWd/kg at top) was achieved using a 500-mm^3 cadmium-zinc-telluride detector.
- The detection limit must be decreased to achieve an unambiguous verification down to 10 MWd/kg with a reasonable measurement time. No reason was found, which could in principle prevent the achievement of this target. As a matter of fact, it is reasonable to expect that the suggested measurement geometry with the improved shielding presented in section 5 should solve this question.
- During the measurement campaigns it was clearly established that the operation of a SFAT device should be implemented using the refuelling machine.

5 SPECIFICATIONS FOR INDUSTRIAL PROTOTYPE

5.1 Mechanical specification

The SFAT should be operated using the refuelling machine. For this purpose a special adapter for installation of the instrument to the refuelling machine should be produced.

The SFAT device consists of a body and an adapter. The body should be watertight, contain the detector and effectuate the measurement geometry and the radiation shield of the detector. The adapter serves for attaching the device to the refuelling machine.

In the design of the industrial prototype the measurement geometry and the special adapter may be integrated into a single device although it is recommended that they should be easily disassembled into these main parts. This allows the use of facility-specific adapters when necessary. Also the total weight and easy transportation of the device from its storage place to the reactor hall should be considered.

The construction of the adapter should permit quick and easy attachment of the cable to the detector unit.

5.1.1 Measurement geometry

The SFAT device should consist of the following two main parts:

- **Adapter**, which should implement an easy attachment to the refuelling machine.
- **Detector unit**, consisting of the detector housing and an air collimator tube with a diaphragm and an additional protective collimator. The air collimator should be a separate component, which is attached to the detector housing for measurements.

The recommended measurement geometry for a tight storage lattice is depicted in Figure 17.

For verification of assemblies closed in hermetic bottles and maybe also for a normal lattice a separate collimator pipe should be designed and manufactured to provide as open a geometry as possible, yet fulfilling a proper shielding against neighbouring assemblies. The need to use different geometries in different verification cases has been anticipated already in the User Requirements, see Annex 3.

5.1.2 Design specifications

A 500-mm^3 CZT detector should be used because of its superior resolution as compared to the scintillation detectors.

The collimator should be hermetically welded after assembling of the inner lead diaphragm, the additional collimator and a gamma ray filter of 2 mm of lead, see Figure 17.

Outer surfaces of the device, which may be in contact with the storage pond water, should not have any pockets or cavities for easier decontamination of the detector unit.

The surfaces should be finished by electropolishing.

The thickness of the detector unit shielding should be about 100 mm of lead below the detector and about 50 mm on the top and the sides.

The inside of the detector housing should be lined with 0.5 mm of cadmium and 0.1 mm of copper for eliminating the secondary x-rays originating from the lead shielding. This lining should cover also the detector entrance diaphragm, see Figure 17.

Special precautions should be taken to suppress sufficiently the background radiation coming from above. The watertight connector of the detector unit should be placed out of the central axis of the detector unit. A labyrinth should be preferred to lead the cable through the top shield.

A special pocket should be made in the detector stainless steel housing for fixation of the control sources (^{137}Cs, ^{60}Co, ^{152}Eu) in front of the inner lead collimator for the system checking and energy calibration. This initial check before each verification campaign should be included in the quality assurance programme. A special lid should close the pocket when the system is not in use or when the control sources are installed for the system control.

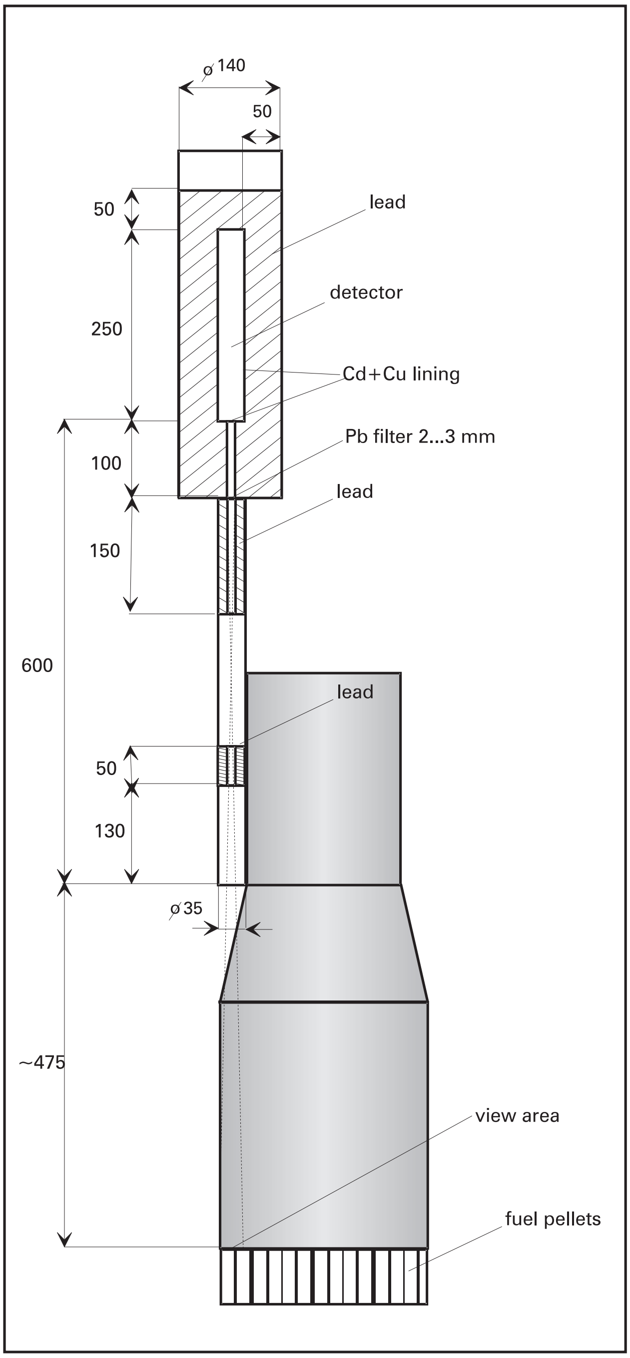

Figure 17. *Recommended measurement geometry for the VVER-1000 SFAT device.*

5.1.3 Materials

All outer metallic surfaces of the device should be of stainless steel.

5.2 Cabling

The detector should be attached to the analyser by a single hermetic cable. The cables and connectors must be watertight and correspond to the types used by the IAEA.

Special attention should be paid to the cableway from the detector unit to the analyser. The construction should exclude the possibility of cable being caught by the TV mast or other moving parts.

5.3 Storage

A special storage case should be devised for the SFAT device and its accessories. The case should be equipped with a seal to prevent tampering during the storage.

A special storage place for the measurement equipment should be defined in discussions with each NPP.

5.4 Considerations regarding the measurement procedure

All demands regarding the measurement arrangements should be included in a special part of a written measurement procedure, which should be drafted during the tests of the prototype and subjected to approval of the IAEA, the Ukrainian State Authority and the operators.

This procedure should include a special part as to collection of preliminary information about the assemblies including the irradiation histories, as such information could assist in planning of the verification measurements.

5.5 Adaptation to other Ukrainian VVER-1000 facilities

During the development and tests of the industrial prototype at other NPPs it is necessary to verify the actual possibilities for using the SFAT at other VVER 1000 units. This means the examination of the possible differences in the refuelling machine design, the possibilities of the rack usage for the SFAT installation, the cableways and the defining of the measurement place.

In preliminary discussions with the Ukrainian VVER-1000 operators it has come out, that two units of the South Ukrainian NPP belong to a different series of VVER-1000 units. They have the refuelling machines of different design than the other NPPs. Special attention must be paid to adapting the SFAT device in the SUNPP units.

5.6 Certification and quality assurance

The certification and approval procedures are described in reference [2].

It is necessary to add that a quality assurance programme should be included in all stages of the device design, manufacturing and use, beginning from the detailed technical design up to regular operational checks during its routine use.

5.7 Data collection hardware and analysis software

As indicated in the evaluation of the results, for a SFAT device based on a large volume CZT detector, any commercially available multi-channel analyser and the software able to control the analyser and able to evaluate the areas of individual peaks could be used. E.g. the IAEA standard MMCA and its software (SPEC or WINSPEC) should be applicable. The applicability of this instrumentation and software will be tested during the prototype tests in collaboration with the IAEA.

5.8 Recommendations for next generation prototype design and fabrication arrangements

It is recommended that the task should be continued by design and fabrication of a next generation prototype. This prototype should fulfil all recommendations given in this report as regards the operation by the refuelling machine, detector selection, its shielding and the compatibility to the IAEA standards.

It is recommended that the technical design of the device and the fabrication of the prototype should take place in Ukraine by a company having large experience with the technical services to the NPPs. This phase should be supervised by the SSTC and the FINSP under close collaboration with the IAEA.

This arrangement should guarantee the best fulfilment of the national standards and safety requirements, which should guarantee the acceptability of the device both to the State Authority and to the facility operators.

6 CONCLUSION

An optimised SFAT measurement geometry for a tight storage lattice has been found and an optimised detector choice has been done. Also the handling of the device using the refuelling machine has been found to be the most convenient, most accurate and safest way of operating the device.

A specification of a SFAT device is given which should solve all verification cases possible to solve using a SFAT type device. The only case, which remains unsolved so far, is the case of assemblies closed in hermetic bottles. This should be tested during the test phase of the next generation prototype. As the optimal measurement system has been found it is believed, that if the verification of hermetic bottles proves out to be beyond the capability of this device using a maximally open collimator pipe, it cannot be implemented with any device based on the SFAT principle.

The specifications of the device have been approved by the State Authority of Ukraine and the Zaporozhye NPP. The procedure for the acceptance of the other NPP operators in Ukraine has been started and will be completed during the design and test phase of the second-generation prototype.

The acceptance of the IAEA of the presented SFAT concept is subject to a demonstration to be arranged in spring 2000 at the Zaporozhye NPP. The target of the demonstration will be to demonstrate the safe handling and accurate positioning of the device using the refuelling machine and also to show the ability of the device to verify long-cooled low burnup assemblies. Also the compatibility of the device with the IAEA standard MMCA analyser will be demonstrated.

REFERENCES

1 SFAT Attribute Verification of LWR Spent Fuel. Standard Procedure SG-NDA-33. International Atomic Energy Agency, Vienna, 1991.

2 Nikkinen, M., Tiitta, A., Ievlev, S., Dvoyeglazov, A. & Lopatin, S. Specification of a VVER-1000 SFAT device prototype. Interim report on Task FIN A 1073 of the Finnish Support programme to IAEA Safeguards. STUK-YTO-TR 155. Helsinki 1999. 30 pp. + Annexes 6 pp.

3 Sampo, Advanced Gamma Spectrum Analysis Software, Version 4.00. User's Guide. Logion Oy, Helsinki, 1999.

4 Edition Ten Product Catalog. p. 320. Canberra Industries, Inc. Meriden, Ct. Also see the web address //www.canberra.com.

5 SigmaPlot 4.0 for Windows 95, NT & 3.1. User's Manual. SPSS Inc., Chicago, Il., 1997.

TASK OUTLINE, TASK FIN A 1073 — ANNEX 1

TASK OUTLINE

Date of Printing : 97/0 7128

1. Agency Task ID: FIN A 01073 **SP-1 ID:** 97/OC2-001
Status: Active **Acceptance Date:** 97/07/03

2. Task Title: Implementation Support for SFAT in Ukrainian Nuclear Power Stations

3. Task Category: A

R&D/IS Need and its Priority:

IIBI.5 Development and Implementation of Improved Safeguards at LWRs Essential

4. Safeguards Problem Identification:

4.1 What is needed, why and when:'

Support is needed to implement the Spent Fuel Attribute Tester (SFAT) in Ukrainian WWER-1000 type nuclear power stations. Because of limitations of the transparency of the water in the spent fuel ponds, SEAT devices are needed to verify the spent fuel in these facilities. It is requested to review the results obtained at the IAEA in designing and testing of SFAT for WWER-1000 reactors and to propose design modifications if needed to obtain a standard SFAT design for above mentioned NPSs Related matters like SFAT fabrication, handling and storage, licensing, measurement procedure, and data evaluation should be included and needs to be arranged by FINSP, in agreement with SGOC2. If necessary, the integration of an underwater T V camera into the SFAT should be considered. As a resuir of this task it is expected to have resident SFAT devices ready in all facilities where needed. It should be possible for SGOC to start using the results of this task in 1998.

4.2 How will the task results be used and by whom ?

The results of this task will primarily be used by SGOC to perform safeguards inspections in Ukrainian WVIER-1000 type nuclear power stations. If suitable, results to be obtained under this task may be used by SGTS in implementing SEAT devices in other NPSs.

43 Consequences if task is not performed:

The work would have to be done by Agency staff. Due to limited human resources, this would lead to a considerable delay in implementing SFATs in Ukrainian NPSs.

5. Agreed Work Outline

5.1 Major task stages with timing:

Time count in months after acceptance of task:

PHASE 1

o IAEA User Requirements - Month 1

o Finnish SP to review IAEA results on WWER-1000
SFAT design and implementation;

o Summary and recommendations, proposal of workplan - Month 2

o Finnish SP to organize joint SFAT test and demonstration
in Ukrainian facility using adapted IAEA device - Month 4

o Finnish SP to draft technical requirement specifications for standard SFAT design.
handling, verification procedure, licensing and data evaluation
including integration of underwater TV system if required to be agreed between
IAEA, State Authority and Operators - Month 7

DECISION POINT: The system to be agreed between IAEA, Finnish SP, Operators.

PHASE 2

o Selection of commercial supplier

o Design and fabrication of commercial prototype device (device to be
funded by the IAEA); design drawings and draft plant
specific handling and verification procedure - Month 10

o Finnish SP to organize joint acceptance test of commercial prototype
and verification procedure - Month 11

o Evaluation of test results, identification of design modifications if any - Month 12

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ANNEX 1 TASK OUTLINE, TASK FIN A 1073

PHASE 3
o Finnish SP to supervise production, deployment and commissioning
of all SFAT devices needed (11 pieces) in Ukrainian facilities - Month 16
Complete task documentation - Month 19

5.2 Expected task completion date: 1998/11

5.3 Initially estimated duration in months: 19

6. Estimated Costs

6.1 To the IAEA to conduct the task:

Person-months: 2 **Person-trips:** 3
Other costs in US$: $110,000.00 **Total costs in US$:** $126,000.00

6.2 To the Support Programme (SP) to conduct the task

Person-months: 10 **Person-trips:** 4
Other costs in US$: **Total costs in US$:** $130,000.00

Remarks:

7. Divisions Involved:

7.1 Requestor Division / Section / Person:
SGOC / OC2 / Charlier

7.2 End User Division(s) I Section(s): SGOC / OC2

7.3 Support Division(s) / Section(s): SGTS / TED

7.4 Responsible Division I Task Officer: SGOC I Charlier

7.5 Alternate Task Officer: Leicman

7.6 Task Specialist($): Arlt

8. RelatedTask(s):

9. SP's Task Contact Person(s): STUK
Finnish Centre for Radiation and Nuclear Safety
Contactperson: M. Tarvainen

10. Task Status Information

10.1 Task Result Date:

10.2 Task Result:

11. Use of Task Results

11.1 Date of Report on the use of results:

11.2 Description of the use: Use Code

11.3 Is a follow-up Report due' No

SPRICS-Support Programme Information and Communication System FIN A 01073 Page2

WORK PLAN, TASK FIN A 1073, REVISED VERSION 20 JANUARY 1999 ANNEX 2

Task FIN A 1073 Revised version 20 January 1999
A. Tiitta FINSP

WORK PLAN

1 Specification of the VVER-1000 SFAT device

Responsibility: FINSP (collaboration with IAEA, Operators, MEPNS/NRA and SSTC)

Deliverables: Specification report (February 1999) including preliminary evaluation of the performance, preliminary verification procedure, acceptance criteria

Decision point: Acceptance of IAEA, FINSP and Operator
March 1999

2 Evaluation of the detector alternatives

Measurement campaign to evaluate the detector alternatives (NaI, CdTe, BGO) in the case of a tight storage rack, long cooling time, low burnup fuel assemblies (Zaporozhye units 1 or 2).

Responsibility:
- Purchase of CdTe detector and cable: FINSP (A. Tiitta, January 1999)
- Measurement campaign arrangements: IAEA (Zendel to discuss in Ukraine in January with the SSTC and Zaporozhye Operator)
- Checking the test SFAT hardware: SSTC (S. Iievlev, February 1999)
- Measurement campaign (A. Tiitta and S. Iievlev, April 1999)

3 Prototype design and manufacture

Contract between the FINSP, Operator and SSTC about the design, manufacturing and licensing of the prototype.

Responsibility
- Contract: FINSP (A. Tiitta)
- Design and manufacturing: SSTC and Zaporozhye NPP (based on contract between FINSP and Ukrainian Party)
- Licensing: SSTC and Zaporozhye NPP (based on contract between FINSP and Ukrainian Party)

April - August 1999

ANNEX 2 WORK PLAN, TASK FIN A 1073, REVISED VERSION 20 JANUARY 1999

4 Acceptance test

Responsibility: FINSP (A. Tiitta) in collaboration with IAEA, SSTC, MEPNS/NRA and Zaporozhye NPP
Deliverables: Test plan, test report, evaluation of test results, final design documents, final verification procedure, final operation manual, acceptance test procedure for production devices
Responsibility

- Test plan: IAEA
- Practical test arrangements: SSTC (S. Iievlev)
- Test report, FINSP (A. Tiitta)
- Final design documents: Zaporozhye NPP
- Final verification procedure: IAEA
- Final operating manual: Zaporozhye NPP
- Acceptance test procedure for production devices: Zaporozhye NPP and SSTC

September - October 1999

5 Production of the SFAT devices for Ukrainian VVER-1000 facilities

Responsibility

- Contract:: IAEA
- Manufacturing: SFAT manufacturer (based on contract)

Deliverables: SFAT devices as ordered by the IAEA

November 1999 - January 2000

6 Commissioning of the devices at the facilities

A separate commissioning plan must be drafted in collaboration with the IAEA, NRA, SSTC and Plant Operators

Responsibility: IAEA

Deliverables: SFAT devices commissioned for use at the specified facilities.

7 Final report

Responsibility: FINSP (A. Tiitta)

Deliverable: Final report

February 2000

ANNEX 3

User Requirements for Modified Spent Fuel Attribute Tester (SFAT) for Ukrainian VVER-1000 Reactors

I. Introduction

There is a need for a rugged, transportable, spent fuel attribute tester to make qualitative attribute tests on spent fuel assemblies.

This SFAT should be used in the cases when ICVD is unable to provide an answer for the SF attribute, mainly for VVER-1000 reactors in Ukraine.

II. Intended Application

The SFAT would serve as a verification instrument for spent fuel stored in ponds at VVER-1000 facilities for:

A. long cooling time items;
B. low burn-up items;
C. fuel in closed containers/bottles.

The problem of spent fuel items stored in closed containers or bottles should also be considered as a target. For case (c), the user can accept a different geometry for verification.

Before routine use may start, the SFAT must pass the acceptance tests for a routine use instrument. This includes meeting the system technical and safety specifications and undergoing a formal usability test or its equivalent in terms of field exercises.

The SFAT will be the instrument of choice for inspection gamma measurement applications requiring transportability, ease of use and durability. This includes attribute measurements desirably for fission products contained in spent fuel assemblies designed for VVER-1000 reactors. These are normally stored underwater in the spent fuel pond, or in a spent fuel basket/container, filled with water. The system should be able to distinguish between fuel and non-fuel items, including in the presence of contaminated water.

III. Required Performance

A. By positioning the SFAT above the fuel assemblies, above other similar items or above containers in VVER-1000 spent fuel ponds, the system should be capable of:
   1. Identifying, in situ, spent fuel through low or medium resolution gamma spectrometry;
   2. Determining the spent fuel presence in individual fuel assemblies in the SF pond;
   3. Determining the spent fuel presence in closed containers or bottles, in this case another verification geometry may be accepted;
   4. Provide y/n answer in-situ for each measurement, regardless of the condition of contamination of water in the pond.

ANNEX 3 User Requirements for Modified Spent Fuel Attribute Tester (SFAT) for Ukrainian VVER-1000 Reactors

B. The system shall be designed in such a way that:
   1. it has optimum size and weight and is acceptable to the operator;
   2. it is rugged, capable of transport with special transport container, which should be provided;
   3. it allows for simple installation into the refuelling machine or other operator accepted equipment, fast turn on and it is easy to make it available for operation;
   4. has diagnosis capabilities and indication of operational problems;
   5. is waterproof and can be stored under water when not in use;
   6. is easy to be decontaminated on site.

IV. Facility details and Installation Requirements for any Facility Specific Applications

The technical specifications of VVER-1000 SFAT should be in line with State (Ukraine) and facility safety regulations. The conditions are described in documents issued by Ukraine Authorities and nuclear facilities in Ukraine in which such an instrument is to be used: RKZ1 to 6, RKU1 to 3, RKHl, RKR3.

The system should be useable in conditions of the environment typical to these facilities including power supply, radiological, safety hazard matters.

V. Operating Requirements

The measurement electronics will need to operate for up to 8 hours on back-up batteries if AC not available and provide sufficient data storage for a typical inspection. The temperature and humidity range should equal the conditions specific to spent fuel pond areas of VVER-1000 facilities and be environment specific in VVER-1000 reactors.

VI. Reliability and Maintenance

The SFAT should be highly reliable with a mean time between failure (MTBF) of better than 3 years (depending on the frequency of usage). The SFAT should have modular design allowing simple and quick maintenance on the spot through modular replacement of the detector sensor package. A person responsible for maintaining the equipment should be established. While the project progresses, in consultation with SG-TCS, SG-TIM, maintenance requirements and performance monitoring questions are to be provided.

VII. Data Acquisition and Processing

IAEA standard equipment should be used.

The system shall carry out the following functions:
1. Collect gamma-ray spectra and determine the energy and presence of prominent lines;
2. Determine the presence of spent fuel;
3. Convenient identification and storage of individual measurements;
4. Connectable to a computer for review or print out of measurements.
5. The necessary acquisition time should be minimised in order to reduce inspection time.

User Requirements for Modified Spent Fuel Attribute Tester (SFAT) for Ukrainian VVER-1000 Reactors

ANNEX 3

VIII. Authentication

SFAT shall be operated in an attended mode. No authentication is necessary. The system should satisfy Agency requirements with respect to tamper indicating – i.e. provisions to be kept under seal, etc.

IX. Calibration

Upon completion of detailed tests of its performance characteristics, the system should be calibrated for various sensor modules (e.g. CdTe or NaI). The calibration should be done in such a way that the reproducibility should be achieved simply by turning on the system. The system calibration should be easily monitored.

X. Documentation

A paper master and electronic copies in Word 95 (or other acceptable text editor) of the following documents should be supplied to the Agency:

A. Functional Requirement Specification
B. Acceptance Test Plan
C. Design Specifications
D. A Quality Assurance Plan (this is optional, but consideration should be given if the development warrants this document)
E. Safety Evaluation Documentation
F. An Operating Manual to the Agency format
G. A Maintenance Manual
H. Software Documentation.

A short procedure sheet should also be foreseen. In addition, system documentation shall be available for service and repair and for NPP operators. Training material for use at the Agency shall be available and training shall be given to inspectors.