SKI Report 96:23

Feasibility of Gamma Ray Verification of Non-standard Fuel Items at CLAB

Lars Hildingsson
Göran af Ekenstam
Matti Tarvainen
Antero Tiitta

March 1996

ISSN 1104-1374
ISRN SKI-R--96/23--SE

SKI
STATENS KÄRNKRAFTINSPEKTION
Swedish Nuclear Power Inspectorate

SKI Report 96:23

Feasibility of Gamma Ray Verification of Non-standard Fuel Items at CLAB

Lars Hildingsson [1]
Göran af Ekenstam [1]
Matti Tarvainen [2]
Antero Tiitta [3]

[1] Swedish Nuclear Power Inspectorate,
S-106 58 Stockholm, Sweden

[2] Finnish Centre for Radiation and Nuclear Safety,
P.O. Box 14, FIN-00881 Helsinki, Finland

[3] Technical Research Centre of Finland,
P.O. Box 1404, FIN-02044 VTT, Finland

March 1996

IAEA Task ID JNT 598

This report has been prepared by the Swedish and
the Finnish Support Programs to IAEA safeguards.

Abstract

Two measurement campaigns have been arranged at the CLAB long term storage facility in Sweden with the final goal to develop a gross defect method for the verification of low burn-up, long cooled spent fuel assemblies as well as fuel scrap and other non-standard fuel items stored in closed containers. During the first campaign gross gamma rates of different fuel were measured. During the second campaign gamma spectrometric (NaI and HPGe) measurements as well as dose rate measurements were performed of different type of fuel assemblies and closed containers stored at the CLAB storage area using a long air filled collimator pipe.

The result of the test is that the non-standard fuel items stored at CLAB can be verified for gross defect by using proper gamma spectrometric detector equipment. The detector needs to be well shielded from the radiation of neighbouring assemblies by the use of a collimator pipe.

The measurements were carried out under the task JNT 598 of the Swedish and Finnish support programmes to the IAEA safeguards.

Key words: Safeguards, spent fuel verification, non-standard fuel items, SFAT, CLAB

Sammanfattning

Två kampanjer med gammamätning på bestrålat bränsle har genomförts vid förvaringsanläggningen CLAB utanför Oskarshamn. Mätningarna har haft som syftat att utveckla en verifieringsmetod för bestrålade bränslepatroner med lång avklingningstid och låg utbränning såväl som för bränsle som lagras i slutna behållare. Under första mätkampanjen mättes gross gamma värdet för olika bränslekassetter. Under den andra kampanjen användes NaI-, HPGe- och dosdetektorer tillsammans med ett luftfyllt kollimatorrör för att genomföra mätningar på bränslepatroner och slutna behållare.

Resultaten visar att det undersökta bränslet på CLAB kan verifieras för gross defekt om gammaspektrometrisk mätutrustning av tillräckligt hög kvalitet används. Det krävs att detektorn skärmas från strålningen från närliggande bränslepatroner med hjälp av ett kollimatorrör.

Mätningarna utfördes under projekt JNT 598 inom ramen för det svenska och finska stödprogrammen till IAEA's safeguard.

Table of contents

1. Introduction

Spent nuclear fuel in Sweden is shipped to the Central Interim Storage Facility for Spent Nuclear Fuel (CLAB) outside Oskarshamn awaiting a future deposition in a deep geological repository. The total amount of nuclear material is accumulating and CLAB has today far more fissile material than any other Swedish facility. With time it is becoming increasingly difficult to verify the low burn-up BWR and PWR fuel using the IAEA standard instrumentation. There is also a significant amount of nuclear material at CLAB, in the form of non-standard spent fuel. This material can not be verified using ICVD techniques and can not be moved to a low background area for special NDA measurements. Time constraints, pool capabilities and operator handling methods make it necessary to perform the verification without moving the fuel.

The LWR fuel at CLAB is placed in storage canisters containing BWR fuel (16 or 25 assemblies in each canister) or PWR fuel (5 or 9 assemblies in each canister). The canisters are loaded in the CLAB receiving area and then lifted down to the storage area below ground level, see Figure 1. Although densly packed, this fuel has normally been verified with the Cerenkov Viewing Device ICVD, during routine inspections.

In addition to the standard fuel there are fuel assemblies from the decomissioned Ågesta pressurized heavy water reactor (PHWR) which was in operation between 1963 - 1974. The Ågesta spent fuel is of three different main designs. The assemblies have a burnup of 1060 - 10825 MWd/tU and with the present Mark IV ICVD, commonly used by IAEA, it is not possible to observe the Cerenkov glow[1].

There are also other non-standard items at CLAB containing spent fuel, such as closed rod cassettes, containers with leaking assemblies and closed containers with fuel scrap. These are not possible to verify with the ICVD.

The non-standard items call for development of improved verification methods. It has been suggested that the Spent Fuel Attribute Tester, SFAT (Tarvainen et al., 1994) could be an alternative gross verification instrument. One version of SFAT has a detector housing with a NaI detector in a lead shield and with a 1.5 m long air filled collimator pipe attached to it. It is submerged in the pond vertically above the fuel assembly to be verified. The emission of gamma radiation from fission and activation products is used for safeguards conclusions.

This paper presents results from an investigation of the gamma radiation from spent fuel (standard and non-standard) in the storage area at CLAB. The pupose has been to check the presence of any radiation from ^{137}Cs and ^{60}Co. It also aimed at comparing the quality of spectra recorded with different types of detectors. The result of the investigation should be used for a discussion of the feasability to use SFAT for verification of non-standard fuel at CLAB and as a basis for recommendations to IAEA.

[1] Sensitivity improvements of the ICVD are the subject of a joint Swedish and Canadian task JNT A00704

2. Equipment

Gross gamma measurements during the first campaign (5 - 6 February, 1992) was performed using a dose rate meter (SaphymoPhy IF104, probes SEC 004, SHF-IF104) that had been absolute calibrated for gamma radiation (^{60}Co) at the standard dosimetry laboratory of STUK. The probe and connecting cables were placed in a plastic sleve before being inserted into the pond water.

The collimator pipe used in the second campaign (20 - 21 April, 1994) consisted of a four segment stainless steel tube with a total lenght of 8800 mm and with an inner diameter of 50 mm. The segments were bolted together and standard O-rings were used to keep the pipe water tight. Care was taken so that the design and handling of the collimator complied with the facility and national safety rules. A schematic drawing of the collimator is shown in Figure 2.

The whole collimator pipe was assembled in the storage area. During the measurements it was hanging vertically from the hook of the bridge service crane. A detector was placed on top of the collimator pipe above water level and the bottom end of the pipe was placed below the water surface close to the top of the assembly to be measured. The collimator placed over a rod cassette in the pond is shown in Figure 3.

The equipment used for the high resolution gamma measurements included a portable HPGe detector (Ortec) with a spectroscopic amplifier and power supply, fast ADC (Canberra 8077) and a PC (IBM PS/2 P70) including an add-on MCA card (Canberra S100). Gamma spectrometric equipment used for NaI measurements included a 2"x2" NaI detector (Harshaw) connected to a portable multichannel analyser (PMCA, Ortec 7500a). Gamma dose rates at the upper end of the collimator pipe were measured with a dose rate meter (SaphymoPhy 6150 AD3). Photographs of the electronics set-up and the detectors are shown in Figures 4 - 7. For energy calibration, certified sources of ^{137}Cs and ^{60}Co were used.

3. Measurements

3.1 Gross gamma measurements

Before the measurements selected storage canisters were moved to an empty part of the pond in the storage area. Each canister was surrounded by empy positions. This means that the nearest neigbouring canister was at least 75 cm away in order to reduce interference. Measurements of the gross gamma rate were then performed by lowering the probe into the pond. The gross gamma rate was measured at different heights above one fuel assembly in each storage canister at vertical positions ranging from the top of the fuel assembly up to 2.5 m above. The relative vertical and horisontal probe position could be measured with a precision of +/- 3cm.

In some cases the gross gamma rates were measured outside the storage canisters at vertical positions corresponding from the top of the fuel assemblies down to the bottom of the assemblies. The horisontal positioning of the probe was in this case less accurate due to the storage rack construction.

Background measurements were made by placing the probe 5 m or more above the fuel.

The measurements included one PWR assembly from the Ringhals 4 reactor, one BWR 8x8 assembly (without fuel channel) from the Barsebäck 1 reactor, three Ågesta assemblies of different types; Types I and II have 19 rods and type III has 5x5 rods. In addition, a closed rod cassette and scrap containers were measured. See Figure 8 for schematic drawings of some assembly types measured.

The measured rod cassette was a closed container with an interior similar to a BWR fuel assembly with spacers. It contains 53 rods. The top lid has the same type of handle as a BWR fuel assembly.

The scrap material stored at CLAB is placed in closed cylindrical boxes (Holmér et al., 1990). A total of twelve boxes are placed in a scrap container in three layers, see Figure 8. The size of a container is similar to that of a PWR assembly. The boxes and containers were packed at the Studsvik Research Centre and CLAB has no instrumentation for opening and closing them.

In one case the gross gamma rates were measured above an empty canister position surrounded by filled BWR canisters. This empy position was then filled with one storage canister containing Ågesta fuel and scrap containers. Measurements had previously been done on this canister when it was isolated. New measurements were then made to estimate the background contribution from neigbouring canisters.

Schematic drawings of the gross gamma measurement points for each canister are shown in Figure 9.

3.2 Gamma spectrometric measurements

In the gamma spectrometric measurement the collimator pipe was inserted into the pond water and positioned by carefully moving the bridge and the manipulator crane. The bottom of the collimator was lowered so it touched gently the handle or the top plate of the assembly/container. Measurements were then done at different heights and different positions. The horisontal position of the collimator could be determined with a precision of +/- 3 cm or better and the vertical position within +/- 1 cm.

The gamma rays were collected in a detector placed on the top part of the collimator. The NaI and the Ge detectors as well as the dose rate meter could easily be interchanged without moving the collimator. The collected gamma spectra from the Ge-detector were stored on the PC for later off-line analysis. The NaI spectra were collected on the PMCA and written on tape for further analysis.

The spectrometric measurements covered the same type of fuel that had been used for the gross gamma rate measurments. In addition a closed container with a leaking PWR fuel assembly and an irradiated BWR control rod were measured. Schematic drawings of the measurement points are shown in Figure 10.

4. Results of the gross gamma measurements

The measured gross gamma rates at different distances above the assemblies are presented in Table 1. A graphic presentation of the result is shown in Figure 11. The rates decreased rapidly with increasing distance until a background level of about 2.5 mrad/h was reached. With the exception of the scrap container the decrease betweeen 0,3 m and 1.5 m followed closely an exponential line with a reduction of approximately 50% for each 11 cm. For distances less than 0.3 m there was an additional intensity superimposed on this exponential decay. For distances larger than 1.5 m the gross gamma rates reached the background level.

The gross gamma rates above the PWR fuel assembly were the higest found in this test and they were up to a factor eight higher than the rates above the BWR fuel assembly. A reason for this could be the different top structures. The handle of the BWR assembly caused a larger distance from the active part of the fuel to the position of the probe. The handle also introduced absorbing material between the probe and the fuel. The higher burn-up for the PWR assembly could also have contributed to the higher rate.

The gross gamma rates above the rod cassette were lower than that of the BWR fuel assembly. Reasons for this could be that the lid covering the cassette absorbed part of the gamma radiation. In addition, the rod cassette contains less material (114,2 kg vs 178,7 kg U^{tot} intitial) and that the average burn-up is lower (10872 MWd/tU vs 35265 MWd/tU) than the investigated BWR fuel assembly.

One Ågesta Type III, 5x5 rod assembly was measured. The gross gamma rate at the top of the handle was about 5% of that of the measured BWR fuel assembly. The lower burn up (8125 MWd/tU vs 35265 MWd/tU) and the longer cooling time (17.7 years vs 3.4 years) were certainly both causing part of this difference. The total amount of material in this Ågesta assembly (55.9 kg U^{tot} initial) is also significantly less than that of the measured BWR assembly (178,7 kg U^{tot} initial).

Two different 19 rod Ågesta fuel assemblies were also measured. They showed a significantly lower gross gamma rate than the 5x5 Ågesta assembly. Even if the burn-up is lower and the cooling time longer, these factors can not alone explain the decrease of intensity by a factor 30 or more. Different fuel geometry and top structures could be an explanation.

Two closed containers with scrap were also measured.The gross gamma rates on top of the lid were even lower than those of the measured 19 rod Ågesta fuel assemblies

and almost a factor 10^5 less than that of the PWR assembly. It can be expected that the gross gamma rates of these types of containers were dominated by the contribution from the top four boxes. However, the detailed compositions of the boxes (amount of material and the burnup) have not been investigated further.

The storage canister F002 was moved from its isolated position to a position fully surrounded by BWR fuel. Gross gamma rates were remeassured at this position and were compared with the gross gamma rates obtained when the position was empty. The results are given in Table 2 and in Figure 12. It is clearly seen that the gross gamma rate above these relatively weakly radiating fuel was domitated by the radiation from the neighbouring canisters. The measurement shows that the radiation from Ågesta fuel assemblies and scrap was completly hidden by the radiation from the neighbours. The measured gross gamma rate is even so high that it is compatible with the rates from a BWR assembly.

The measured gross gamma rates outside storage canisters are listed in Table 3 and shown in Figure 13. The gross gamma rates outside the PWR canister were up to 30 times stronger than the rates outside the Ågesta canister. The local minimum for the PWR canister at -150 cm is probably caused by difficulties positioning the probe due to the storage rack construction. The measured PWR gross gamma rate is compatible with a similar measurement made earlier by the facility (Karlsson, 1987).

5. Results of the gamma-spectrometric measurements

The gamma spectra recorded were analysed in search for the gamma radiation from the decay of ^{137}Cs and ^{60}Co. The 1460 keV transition from the decay of the ^{40}K isotop was also detected due to the detectors not beeng shielded from radiation from the concrete walls. In general, the two transitions of 1173 keV and 1332 keV from the ^{60}Co decay were easily identified in both the Ge and NaI spectra as distinct peaks on a low background. The 662 keV transition from the ^{137}Cs decay is situated in an energy region where the intensity of the Compton scattered gamma rays from ^{60}Co is strong. This made the identification of the ^{137}Cs decay more difficult, especially in the NaI spectra.

In the spectra from the low resolution NaI detector a careful Gaussian peak fit with a second order background was used (Tiitta et al., 1993) to establish the detected energies and intensities. This procedure was necessary to determine the 662 keV transition intensities. In the spectra from the Ge detector the high energy resolution made it possible to use a simpler procedure were the peak areas were determied by the number of counts above a linear background. A summary of the measurement results is given in Table 4.

The measured count rates of the 662 keV transition for the NaI detector is shown in Figure 14 versus the corresponding count rates in the Ge detector. In the ideal case there should be a linear relationship between the count rates in the two detectors resulting in a straight line in the figure. Due to statstical spread and uncertainty mainly in the peak fit of the NaI spectra, the data points are scattered. The two data points deviating most from the strait line are from spectra of PWR assemblies. Their NaI spectra did not show a distinct 662 keV peak, see section 5.3 below. Because of the expected higher significance of the results from the Ge spectra these high resolution spectra were used for the evaluation below.

5.1 Positioning and reproducibility

Count rates at different measurement positions were investigated above one Ågesta fuel assembly (04-130). The collimator was placed directly over the assembly handle and then to the side of the handle above the fuel top plate. In both cases the collimator was positioned 16 cm above the handle. The results indicated a lower count rate for the 662 keV transition when the collimator was placed vertically above the handle as compared to when it was placed aside. The opposite effect was observed for the 1332 keV transition. The handle is an absorber and thus decreased the ^{137}Cs signal. Since the handle is activated it contains high activities from ^{60}Co. This inceased the 1332 keV signal when the collimator was positioned vertically above the handle.

To estimate the reproducability of the system two consecutive measurements were made without moving the collimator on assembly 04-130 at 0 cm relative height. The count rates for both 662 keV and 1332 keV gamma rays differed in both cases less than 5%. Test were also made by moving the collimator between the measurements and trying to place it again in the same position. The measurements made at 13 cm and 16 cm relative heights are two such tests. At the 13 cm level the difference in the 662 keV count rates were 40 %. At the 16 cm level where the statistics is low, the two spectra showed a difference in the count rates of the 662 keV transition of a factor two.

5.2 Influence of water thickness

The variation in detected intensities of the ^{137}Cs and ^{60}Co decays was measured for Ågesta assembly 04-140 as a function of the distance between the handle and the bottom of the collimator. The results for the Ge-spectra are given in Figure 15. The count rates in the 662 keV peak and the 1332 keV peak decreased with increasing distance, that is with increasing water thickness. (The effect of decreased solid angle of the detector caused by the increased fuel-to-detector distance, 16 cm out of a total distance of approximately 8.8 m, is neglected.) The decrease followed closely an exponential decay with a reduction of 50% of the signal for each 9 cm and 16 cm for the 662 keV and 1332 keV gamma rays, respectively.

5.3 Intensities from different types of fuel and non-fuel objects

Five different PHWR Ågesta fuel assemblies of different burnup and cooling time were measured. The count rates were low and measuring times up to 500 seconds were used to get sufficient statistics in the Ge-spectra. Both NaI and Ge spectra showed the 1173 keV and the 1332 keV transitions from ^{60}Co as clear resolved peaks. The 662 keV transition showed up in all the Ge-spectra as a distinct peak on a high background. In the NaI-spectra this transition was a clear peak only in one spectrum while for the other cases the peak fit procedure was needed to resolve any transition. See Figure 16 for a comparison of the Ge and NaI spectra.

To measure background spectra, the collimator was placed in between fuel in one full Ågesta canister, see Figure 10. The 662 keV transition was not detected at this position but the 1332 keV transitions was strong as can be seen in the spectra in Figure 17. It is apparent that the collimator in this case can shield the ^{137}Cs radiation from neigbouring fuel assemblies but not the radiation of ^{60}Co.

Measurements were also done on BWR and PWR fuel assemblies for comparison. One of the PWR assemblies had leaking rods and was stored in a closed container. Examples of spectra are shown in Figures 18 and 19. Both types of fuel assemblies showed distinct peaks from ^{60}Co and ^{137}Cs in the Ge-spectra. The intensity of the ^{137}Cs peak in the Ge-spectra was approximately 10 - 20 times that of the weakest Ågesta assemblies. The relatively short cooling time (2 years) for assembly 2E2 allowed for the observation of gamma rays from other fission products. These gamma rays could not be resolved in the NaI spectra but they interfere with the ^{137}Cs gamma ray and also added to the general background. In the spectra of PWR assemblies a broad structure was seen at the expected position of the 662 keV transition. A firm conclusions of the ^{137}Cs content could thus not be done using the NaI spectra only.

Two closed rod cassettes with BWR rods were also measured.The resulting spectra did not differ in principle from the standard BWR fuel, see Figure 20. The presence of ^{60}Co and ^{137}Cs could clearly be detected.

One closed container with fuel scrap was included in the test. When measured directly over the center of the container no 662 keV transition could be detected. When placing the collimator beside the top lid (see Figure 10) a strong 662 keV transition showed up, see Figure 21. Compared to the fuel assemblies measured, the intensity ratio of the 662 keV transition to the 1332 keV transition was much higher. This is expected if most of the assembly skeleton has been removed and only irradiated fuel scrap is stored. Because of the geometry of the container a large amount of material was blocking the radiation at the center and the collimator had to be placed off center to observe a signal.

Finally, a measurement was made on a BWR control rod. As expected, no ^{137}Cs was observed, only the strong activity of ^{60}Co was detected, see Figure 22.

5.4 Measurement times

It can be of interest estimate of the total time needed to do measurements of this kind. It depends, of course, on the number of assemblies to measure and the statistical significance needed. The here given estimates are based on the present collimator pipe which is not optimised for routine inspection. For a measurement with a HPGe detector the following approximate times can be used:

- Mounting the collimator and the detectors takes approximately 1 - 2 hour.
- Positioning the collimator above an assembly takes 5 - 10 minutes
- Measurement of one assembly takes 1 - 10 min
- Measurement of background takes 1 - 10 min
- Dismantling the set-up takes 1 - 2 hours

The facility operator takes care of the mounting, dismantling and decontamination of the collimator pipe. Positioning the collimator is also done by the operator by driving the bridge and the service crane. The measurement time should allow for collecting sufficient statistics in the peak area so that

$$\frac{\text{peak area}}{3 \text{ sigma}} \geq 1$$

where sigma is the estimated standard deviation in the fitted peak area.

5.5 Personnel doses

The dose rates measured at the top of the collimator were maximum 200 μSv/h. The gamma radiation escaping from the pipe was highly collimated and did not give detectable dose rates to the personnel working on the bridge.

6. Discussion

The verification of irradiated nuclear fuel can be based on the presence of gamma radiation from the fission products. For long cooled fuel most of the fission products have decayed and the 662 keV gamma rays from the ^{137}Cs decay will dominate the radiation. There is also a large contribution from the 1173 keV and 1332 keV transitions from the decay of ^{60}Co. This isotope is produced when the fuel handle, top plate, spacers etc are irradiated. The ^{60}Co radiation is thus not directly connected to the fuel material itself and should not be used for verification purposes.

The gross gamma rate measurement using an ion chamber will not discriminate between these two isotopes. If all fuel rods have been removed from an irradiated assembly and replaced by dummy rods such a gross gamma measurement from the top will register the ^{60}Co radiation from the top plate and the assembly can by misstake be taken for a real irradiated fuel. A radiation profile along the assembly will reveal such a dummy but measuring radiation profiles is difficult or impossible for fuel assemblies in storage canisters at CLAB.

Another problem with the dose rate measurments is the large spread in the dose rates, almost a factor 10^5 between the top of the scrap container and the top of the PWR assembly. The radiation from highly irradiated, relatively short cooled fuel can easily hide the signal from weaker radiating objects. This was found when a canister with Ågesta fuel and scrap containers was moved to a position surrounded by BWR fuel. Storage canisters with the relatively low radiating fuel and containers must be placed in isolated positions in the pond to give a distinct signal. But even in this case, an unscreened ion chamber will detect the background radiation from several neighbouring assemblies within the canister and individual assemblies can not be verified.

With the gamma spectroscopic measurement observations of specific isotopes can be done. The measurement of the Ågesta fuel stored at CLAB gave a significant ^{137}Cs peak after a 500 s measurement time in the high reolution Ge spectra. Although the peak is situated on a high Compton background it can easily be resolved and simple analysing methods can be used. In the low resolution NaI spectra the ^{137}Cs peak is difficult to resolve. An advanced peak fit procedure is needed in order to make a conclusion. Such a peak fit procedure is presently not included in the PMCA of the IAEA[2]. The results from the NaI spectra is also very sensitive to the shape of the background, as for example was found in the measurement of the PWR assemblies.

The long collimator makes it possible to better select the assembly to measure and to screen the radiation from the neighbouring fuel. It also allows to do background measurements between assemblies and in empty positions.

The count rate in the detecor is very sensitive to the position of the collimator. The uncertainty in both horisontal and vertical position introduces count rate differences that are 40% or more. A quantitative measurement of the ^{137}Cs content can thus not be made. This is not necessary since the method tested is ment for gross defect testing based on the spent fuel specific radiation from fission products.

The ^{137}Cs radiation from the fuel scrap in the closed container can be observed with both the Ge and the NaI detectors when the collimator is positioned properly. However, it can be expected that the main contribution to the gamma signal will originate from the four boxes in the uppermost layer inside the container. The other eight boxes can not be detected.

---

[2] Improvement of the peak fit procedures is the subject of task FIN A940

The ^{137}Cs radiation of closed rod cassettes and covered leaking fuel assemblies could be observed with the high resolution Ge detector. The low resolution of the NaI detector was in one case (the covered PWR assembly) sufficient to fully resolve the ^{137}Cs peak.

It can be noted that the large difference in the rates found in the gross gamma measurements (a factor close to 10^5) does not correspond to the same large difference in the measured peak intensities of ^{60}Co and ^{137}Cs.

A non-fuel assembly, like an empty skeleton or an assembly with rods of non-nuclear material may apparently emit gamma radiation. This radiation can consist of scattered gamma rays from neighbouring assemblies. The signals from different type of non-fuel assemblies were not examined in this study.

The number of assemblies that has to be verified to cover the IAEA safeguards criteria can be estimated. There are 222 Ågesta assemblies stored at CLAB with a total content of 47.7 kg plutonium. This makes an average value of 215 gram plutonium per assembly. The amount of plutonium in spent fuel stored in the 18 closed containers (leaking fuel, rod cassettes and scrap containers) is 20.6 kg giving an average of 1144 gram plutonium per container. The number of assemblies/containers to measure, n, can then be calculated from (see e.g. Jaech, 1991):

$n = N(1 - \beta^{x/M})$ where

N is the total number of objects

$\beta = 1 - \alpha$; where α is the detection probability

x = average plutonium content per object

M = 8.0 kg, which is the significant quantity for plutonium.

With a 50% detection probability this gives, rounded up to the nearest integer, 5 Ågesta assemblies and 2 containers to be verified. With a 90 % detection probability the corresponding numbers are 14 Ågesta assemblies and 6 closed containers to be verified. The number of leaking fuel assemblies stored in closed containers at CLAB is expected to increase in the future and the number of such containers to be verified has then to be increased, too.

7. Conclusions

Gross gamma measurements with ion chambers are not recommended for verification purposes of spent fuel in storage canisters at CLAB. This concerns spent fuel assemblies and fuel in closed containers. This is because the radiation from individual assemblies can not be separated and because irradiated metal structures can not be discerned from irradiated nuclear material.

Gamma spectrometric measurements with an air-filled collimator pipe inserted into the pond water offers a complementary method for verifying non-standard fuel items when the Cerenkov glow can not be detected. Also for long cooled low burn-up fuel the Cerenkov glow can be on the detection limit for the CVD instrument and a gamma spectrometric method with a collimator can be used. For fuel in closed containers measurements with a collimator pipe will be the only choice. A gamma spectrometric method is needed if a direct verification of fission products is requested. However, to unambiguously detect the 662 keV transition from ^{137}Cs a HPGe detector has to be used.

Acknowledgements

The authors wish to thank the Swedish fuel waste management company SKB for providing access to the long term storage facility CLAB. We would also like to express our gratitude to the staff at CLAB for their advice and assistence in preparation of the equipment and in performing the measurements.

References

Holmér, A., Hammar, S. and Dybeck, P., *Management of fuel waste from fuel testing programs and postirradiation examination in Sweden*, Studsvik Report NF(P)-90/04, 1990

Jaech, J. L. and Russell, M., *Algorithms to Calculate Sample Size for Inspection Sampling Plans*, STR-261, Rev. 1, IAEA, March 1991

Karlsson, H., *Dosratmätning på fyllda BWR- och PWR-kassetter*, OKG report 8-175/87

Tarvainen, M., Paakunainen, M., Tiitta, A. and Sarparanta, *K. BWR SFAT gross-defect verification of spent BWR fuel*, Report STUK-YTO-TR 72, Finnish Centre for Rasiation and Nuclear Safety, April 1994

Tiitta, A., Kaita, K., Tarvainen, M., *SFAT geometry verification measurements at the TVO KPA-Store*, Report STUK-YTO-TR 55, Finnish Centre for Radiation and Nuclear Safety, July 1993

The Ågesta Nuclear Power Station, A staff report by AB Atomenergi, Edited by B. McHugh, Stockhom, 1964

Tables

Fuel type		BWR	PWR	Ågesta I	Ågesta II	Ågesta III	Rod cassette	Scrap	Scrap
Canister		B438	A083	F002	F002	E006	B348	F002	F002
Fuel id		9313	01C	03-121	06-192	04-130	SS13	F2T06	F2T01
Burnup (MWd/tU)		35265	40437	1510	5615	8125	10872*	16000*	18800*
Cooling time (years)		3,4	4,4	20,7	20,7	17,7			
	Relative height (cm)	(rad/h)	(rad/h)	(rad/h)	(rad/h)	(rad/h)	(rad/h)	(rad/h)	(rad/h)
Background		0,0023	0,0023			0,0021	0,0021	0,0013	
	0	611	5200	1,1	1	34	112	0,0695	0,11
	10	225	904			15,1	53,5	0,0331	
	20	115	344			5,5	22,3	0,018	
	30	51,5	132			3,6	11	0,0096	
	50	12	26			1,14	2,7	0,0044	
	100	0,475	1,3			0,0287	0,122	0,0023	
	150	0,023	0,0315			0,0023	0,0068	0,0019	
	250	0,0026	0,0033			0,0021	0,0021	0,0021	

*Average burnup

Table 1. Gross gamma rates above different types of assemblies.

Fuel type		Empty	Scrap	Ågesta II
Canister			F002	F002
Fuel ID			F2T06	06-192
Burnup (MWd/tU)				5615
Cooling time (years)				20,7
	Relative hight (cm)	(rad/h)	(rad/h)	(rad/h)
Background		0,0023	0,0029	0,0029
	0	304		375
	10	245		303
	20	160		214
	30	108	87,5	103
	40		47,5	
	50	43	32	36,6
	60		22,5	
	80		7	
	100	3,8		3,2
	130		0,515	
	150	0,23		0,261
	180		0,0335	
	250	0,0033		0,0039
	280		0,0039	

Table 2. Gross gamma rates above a basket position that was empty and then filled with canister F002

Fuel type		PWR	Ågesta III
Canister		A083	E006
Fuel ID		01C	04-218
Burnup (MWd/tU)		40437	5310
Cooling time (years)		4,4	17,7
	Distance from top (cm)	(rad/h)	(rad/h)
	0	1860	4
	-50	20300	116
	-100	23300	283
	-150	8870	326
	-200	13400	372
	-300	13600	400
	-350	1400	300
	-400		150

Table 3. Gross gamma rates outside a PWR and an Ågesta canister.

							HPGe data						NaI data						
Measurement no	Canister	Assembly ID	Position	Burnup (MWd/tU)	CT (years)	Distance from handle (cm)	Live time (s)	662 keV (counts/ 100s)	Sigma	S/N (area/ 3sigma)	1332 keV (counts/ 100s)	Ratio 662/1332	Live time (s)	662 keV (counts/ 100s)	Sigma	S/N (area/ 3sigma)	1332 keV (counts/ 100s)	Ratio (662/1332)	Dose rate (uSv/h)
	ÅGESTA I fuel																		
1	F001	03-061	aside handle	1060	23	0	500	264	28	3,1	2690	0.100	490	634	113	1,8	5551	0.114	4,2
2	F001	empty pos				-35	500	101	29	1,2	2768	0.036							
3	E003	03-052	aside handle	1180	23	6	200	157	48	1,1	3096	0.051	487	619	183	1,1	6387	0.097	5,5
4	E003	03-128	aside handle	1190	23	-1	200	209	52	1,3	3343	0.063	485	228	80	0,9	7061	0.032	3
	ÅGESTA II fuel																		
5	F002	06-180	aside handle	4885	23	-4	500	2727	41	22,4	4012	0,68	58	5762	410	4,7	7836	0.735	7
6		06-180	aside handle			16	500	444	30	4,9	3081	0,14	58	1750	360	1,6	6672	0.262	4,5
	ÅGESTA III fuel																		
7	E006	04-130	aside handle	8125	20	0	360	599,4	66,4	3	9120	0.066	942	1165,8	141,4	2,7	17606	0.066	10
8		04-130	aside handle			0	3000	570,7	23	8,3	8978,8	0.064							10
9		04-130	aside handle			6	500	339,8	49,8	2,3	7012	0.048	474	1134,2	293	1,3	15166	0.075	7,5
10		04-130	aside handle			13	1000	244,5	30,7	2,7			963	346,7	131	0,9	10437	0.033	5
11		04-130	aside handle			13	500	174,4	43,4	1,3	5329,4	0.033							
12		04-130	aside handle			16	500	95,2	41,2	0,8	4688,4	0.020	483	492,5	136	1,2	8757	0.056	
13		04-130	aside handle			16	500	191,8	40,4	1,6	4298	0.045							
14		04-130	centre			16	500	62	29,6	0,7	5272,8	0,012							
15	E006	Background					500	0	0		2678,6	0.000	486	-5,1	27595	0	5092	0.000	
	PWR fuel																		
16	G041	39A		14415	10	30	200	2215	157	4,7	11498	0.190	158	9816	1208	2,7	25297	0.388	35
17	C001	2 E2 leaking		35869	2	0	3312	1691	38	14,7	47543	0.036	339	11961	2346	1,7	114882	0.104	69
	BWR fuel																		
18	B348	AA3256	aside handle	23525	11	0	60	5815	225	8,6	14122	0.410	171	14581	818	5,9	31583	0.462	12
	Rod cassettes																		
19	B348	SS10	aside handle	7682	13	0	60	1397	148	3,1	7705	0.180	186	2727	246	3,7	17037	0.160	10
20		SS10	aside handle			-14	200	4410	98	15,1	17403	0.250	52	9640	867	3,7	37773	0.255	17,1
21	B348	SS13	aside handle	10872	13	0	60	2318	172	4,5	9305	0.250	183	5419	384	4,7	20356	0.266	11
	Scrap container																		
22	F002	F2T06	centre			0	500	0	0		2560								3
23		F2T06	aside			-69	60	15005	198	25,1	3663	4,1	56	39584	2086	6,3	7768	5.096	8,5
	Control rod																		
24	L027	control rod				0	209	0	0		13068	0	70	0	0		133394	0	200

Table 4. Summary of the gamma spectrometric measurements including HPGe, NaI and dose rate data.

Figures

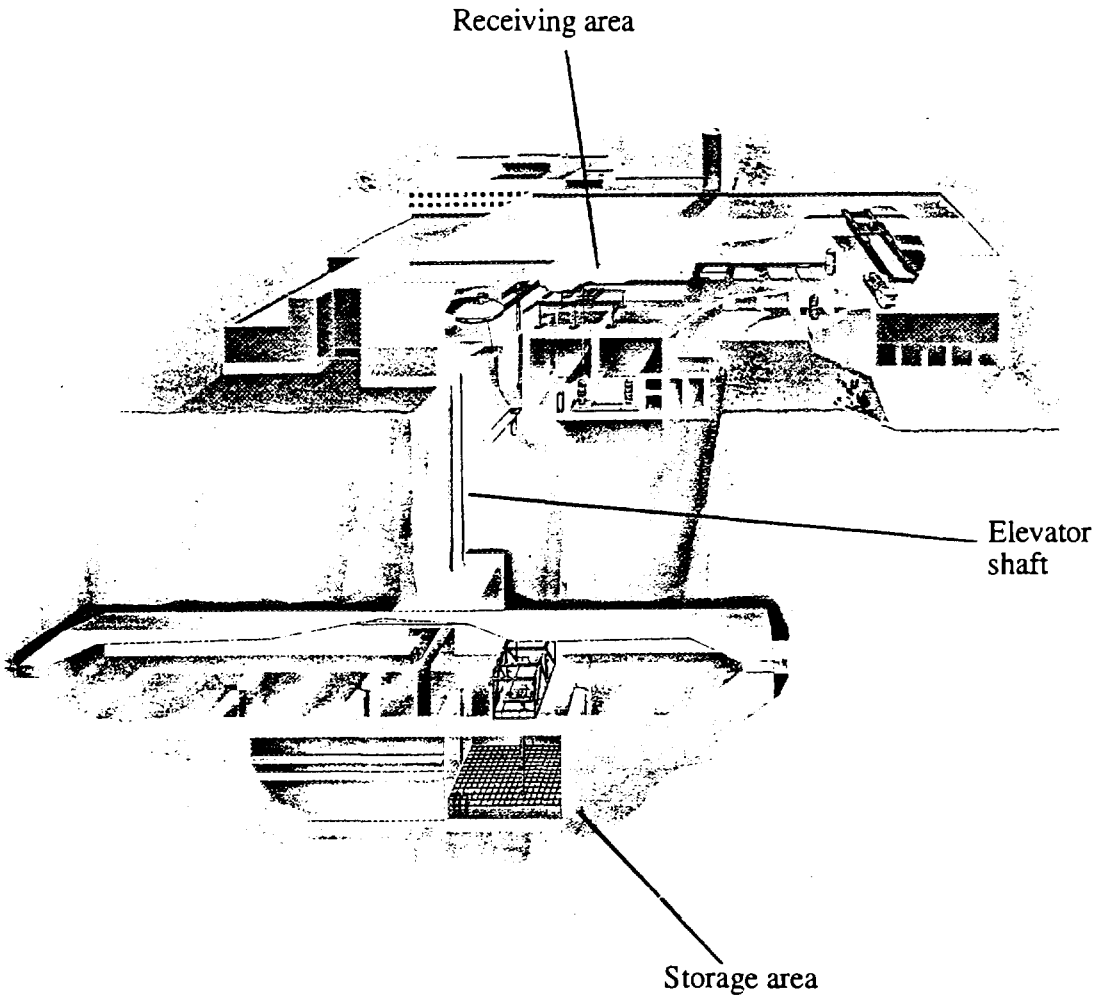


Figure 1. Schematic drawing of the layout of the CLAB long term storage facility. The fuel assemblies enter the facility above ground in the receiving area where they are placed in storage canisters. The canisters are then brought to the storage area below ground through the elevator shaft. All measurements were done in the storage area.

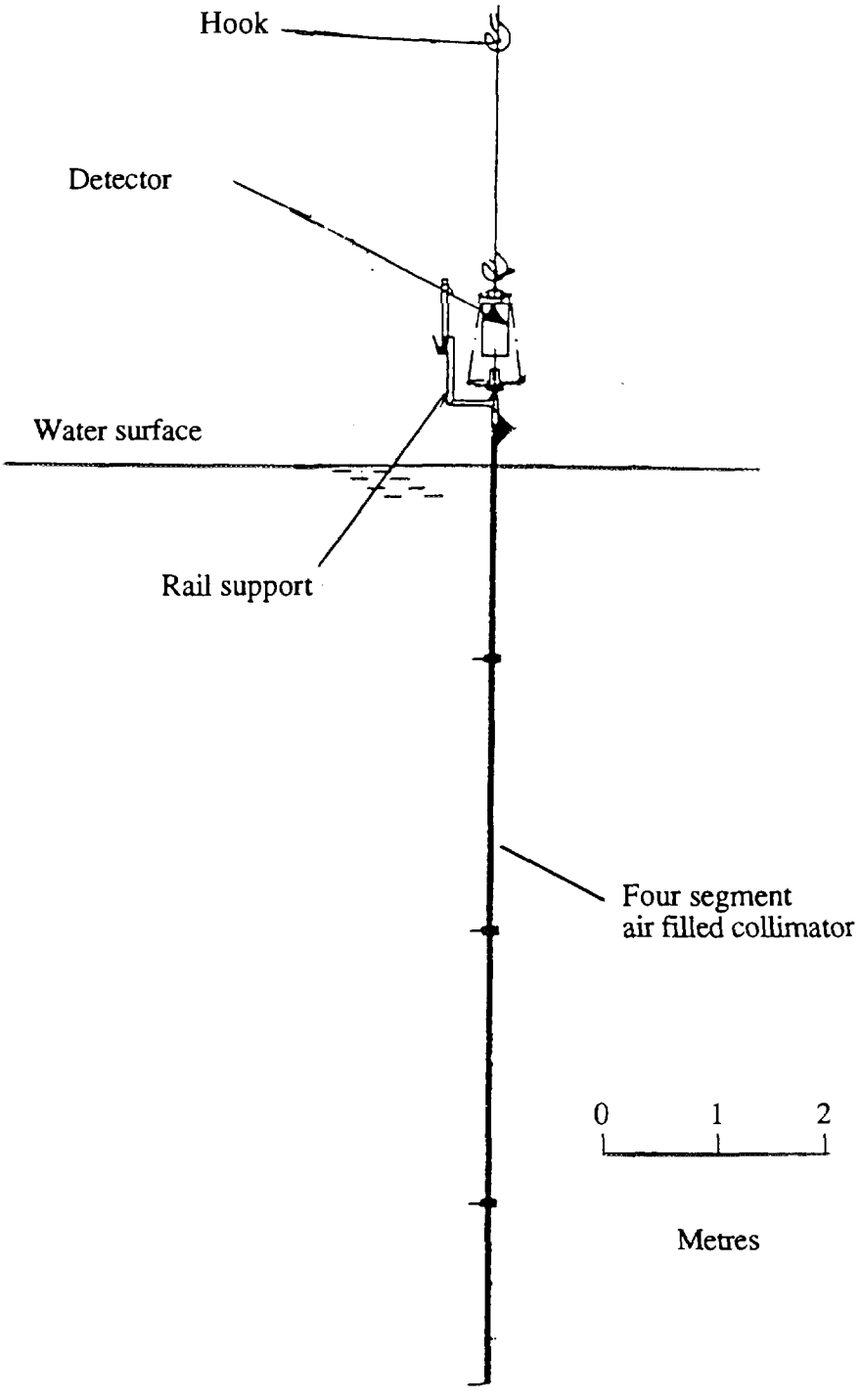


Figure 2. Schematic drawing of the air filled collimator pipe.

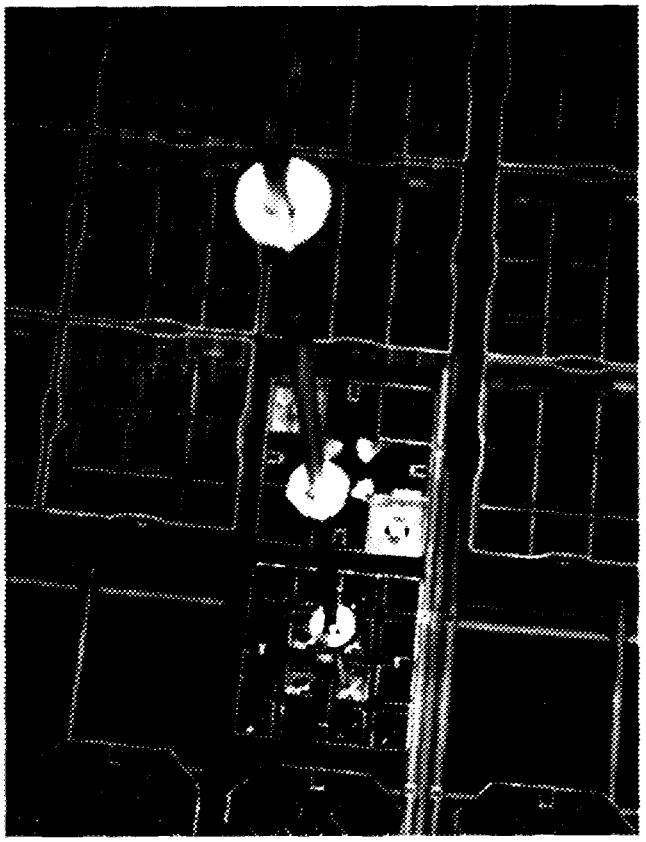


Figure 3. The collimator pipe inserted into the pond at CLAB and positioned above a closed rod cassette.

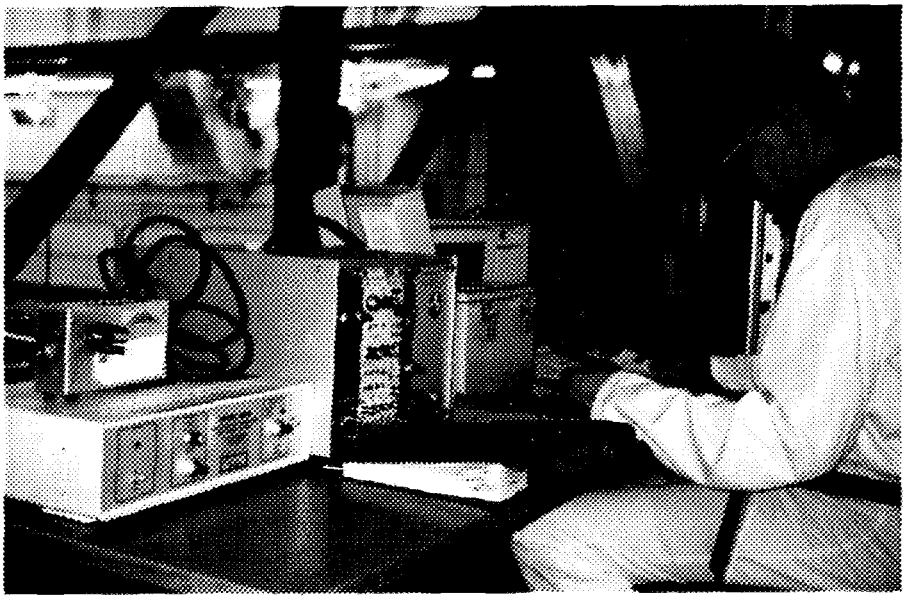


Figure 4. The electronics set-up

Figure 5. The HPGe-detector placed on the top of the collimator.

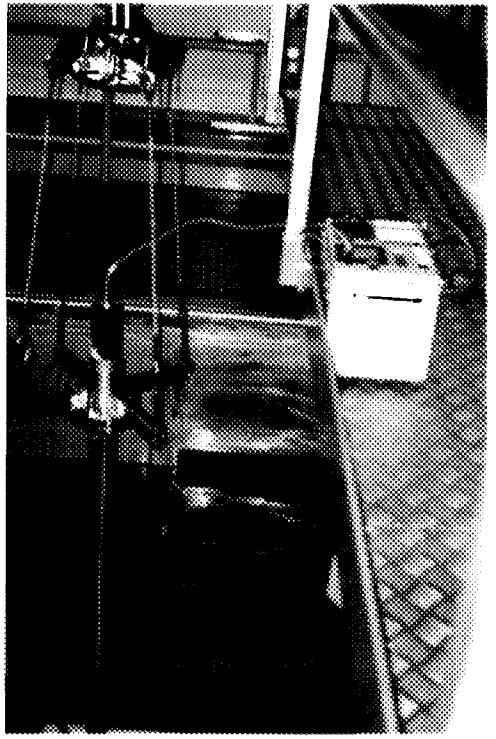


Figure 6.The NaI detector placed on the top of the collimator together with the PMCA on the bridge.

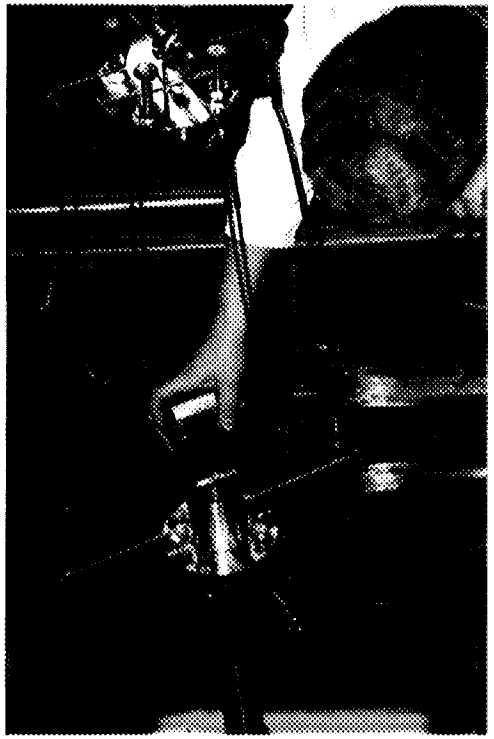
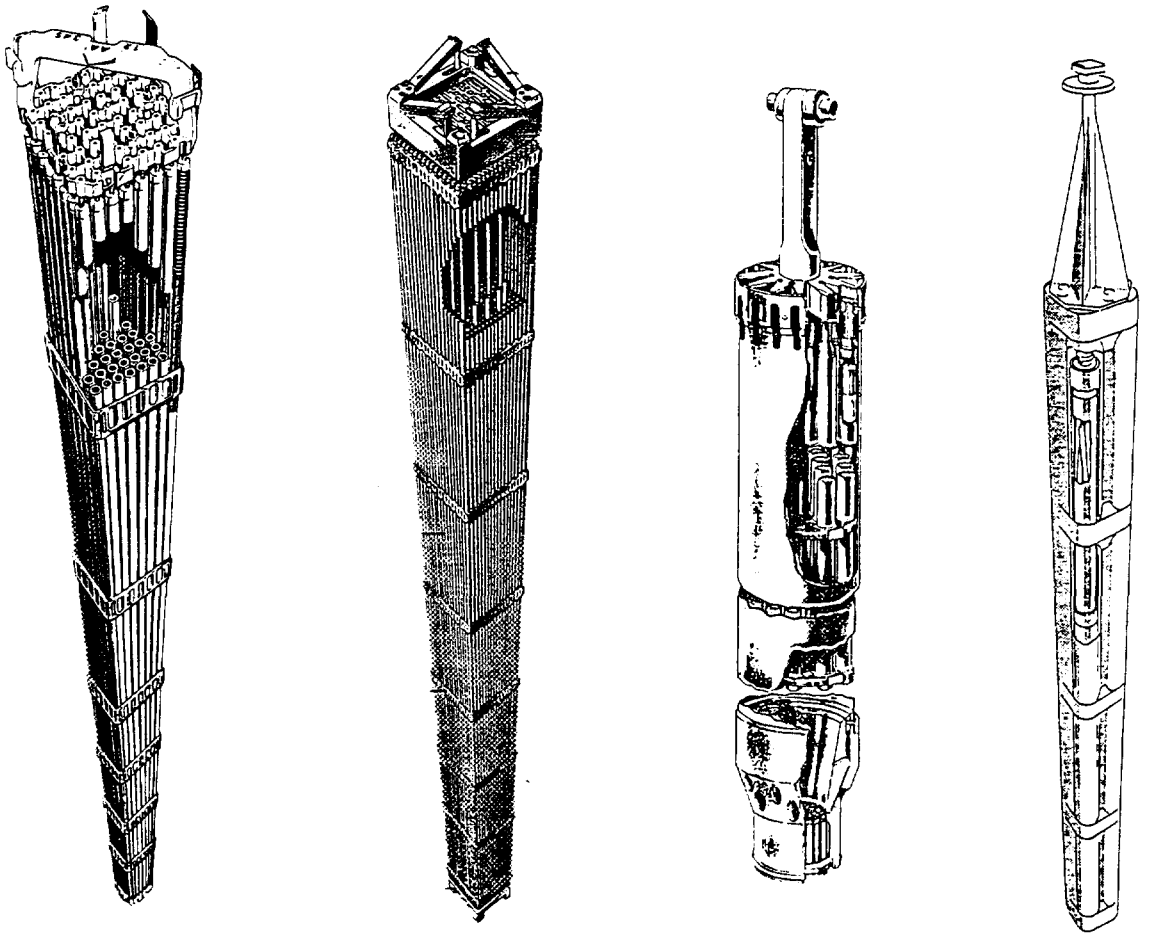
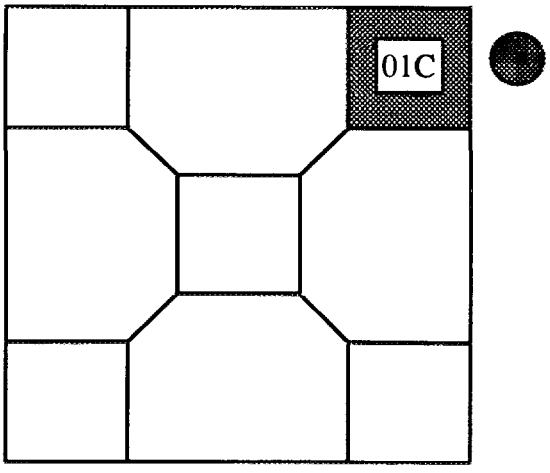


Figure 7. Dose rate measurements being done above the collimator pipe with a handheld dose rate meter.

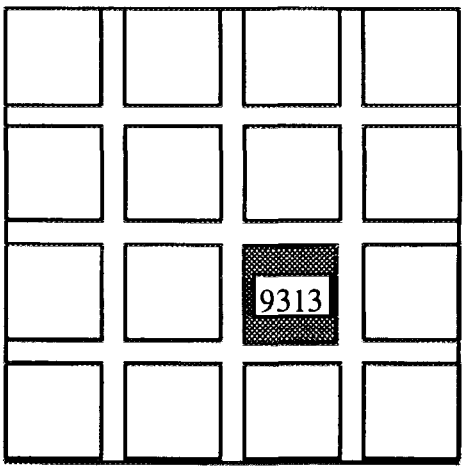


a) BWR b) PWR c) Ågesta Type I d) Scrap container

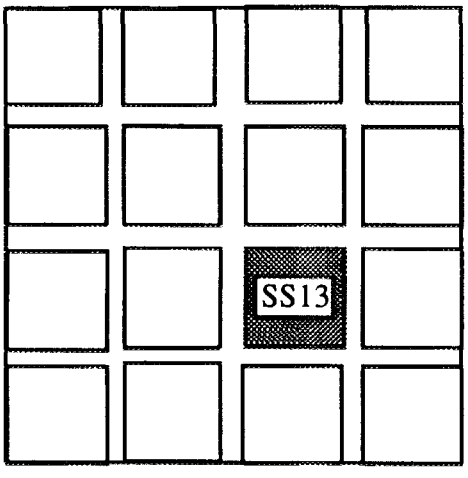
Figure 8. Schematic drawings of the assembly types and containers measured.
a) BWR 8x8 fuel assembly (ABB Atom)
b) PWR fuel assembly (ABB Atom)
c) Ågesta Type I assembly (from McHugh, 1964)
d) closed scrap container with 12 boxes (from Holmér, 1990)



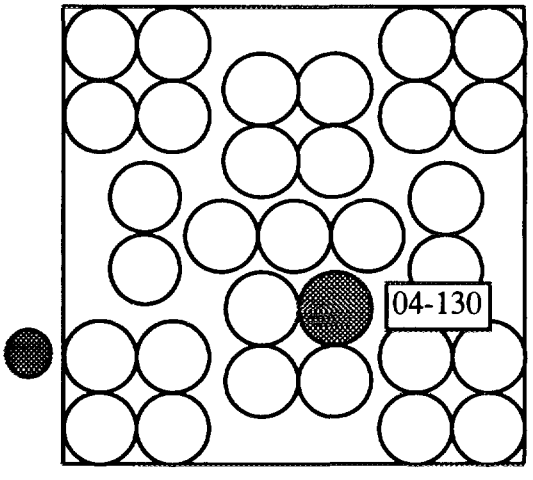
Canister A083



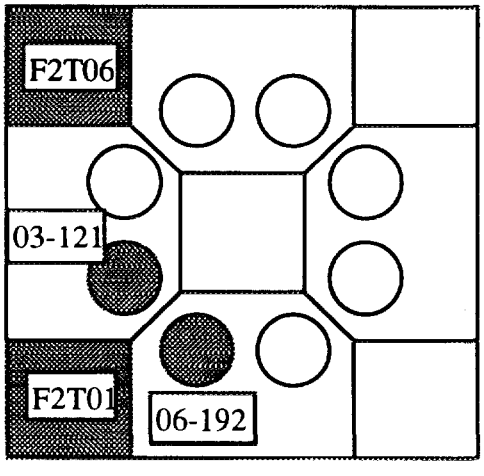
Canister B438



Canister B348

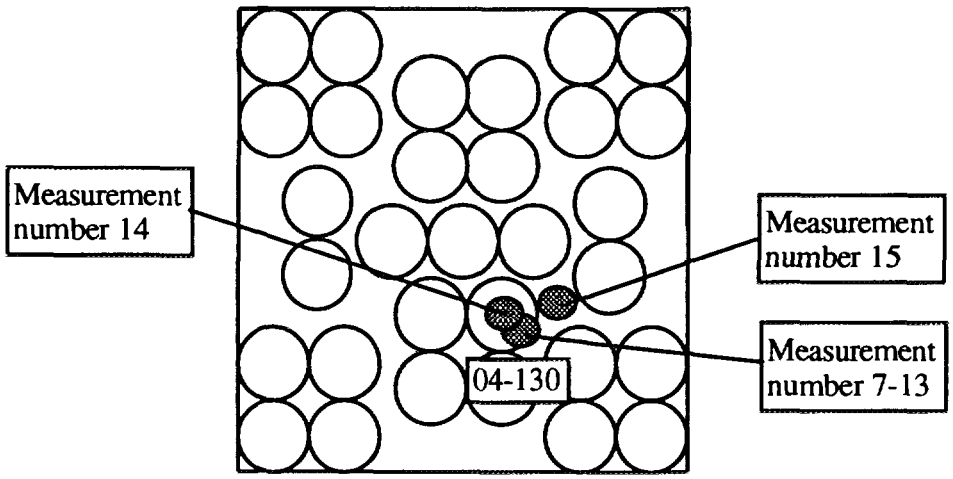


Canister E006

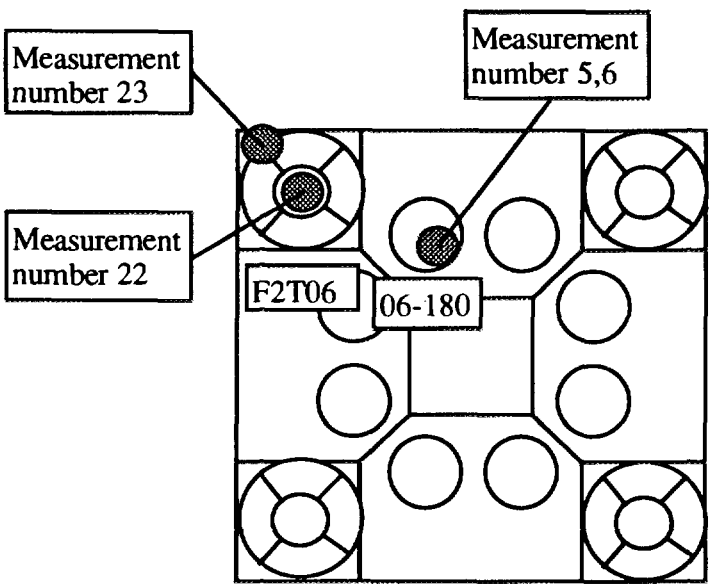


Canister F002

Figure 9. Schematic drawings of the canisters used for the gross gamma measurements. The shaded assemblies/containers were measured on. Shaded circles outside the canisters indicate the probe position when measuring gross gamma rates outside the canisters. The canisters are oriented so that the north wall is up in the figure.



Canister E006



Canister F002

Figure 10. Schematic drawings of two of the storage canisters used for the gamma spectrometric measurements. The shaded circles indicate the position of the collimator pipe. The canisters are oriented so that the north wall is up in the figure. Measurement numbers refer to Table 4.

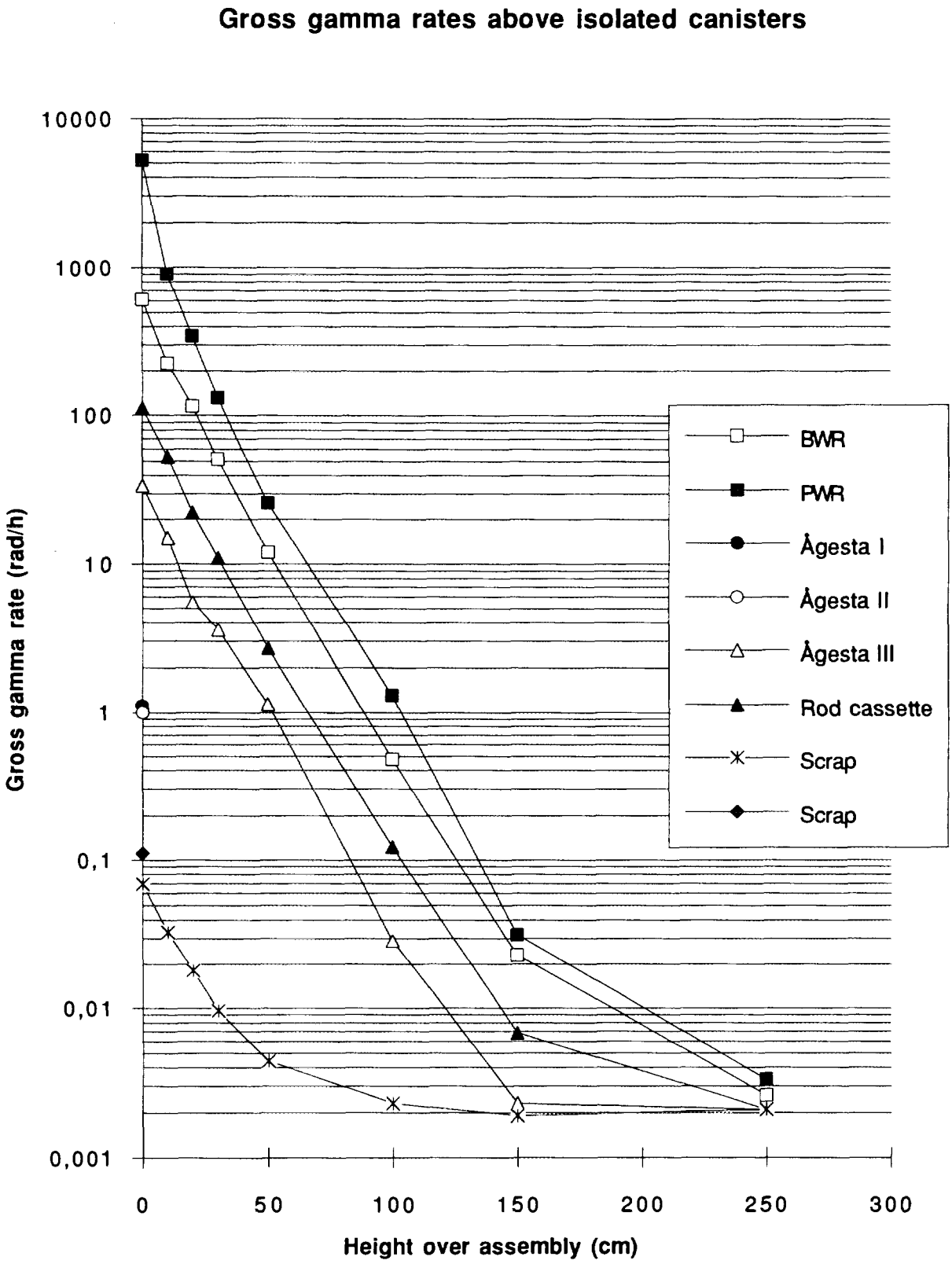


Figure 11. The gross gamma rates as a function of the distance from the top of the assembly. All assemblies were in isolated canisters.

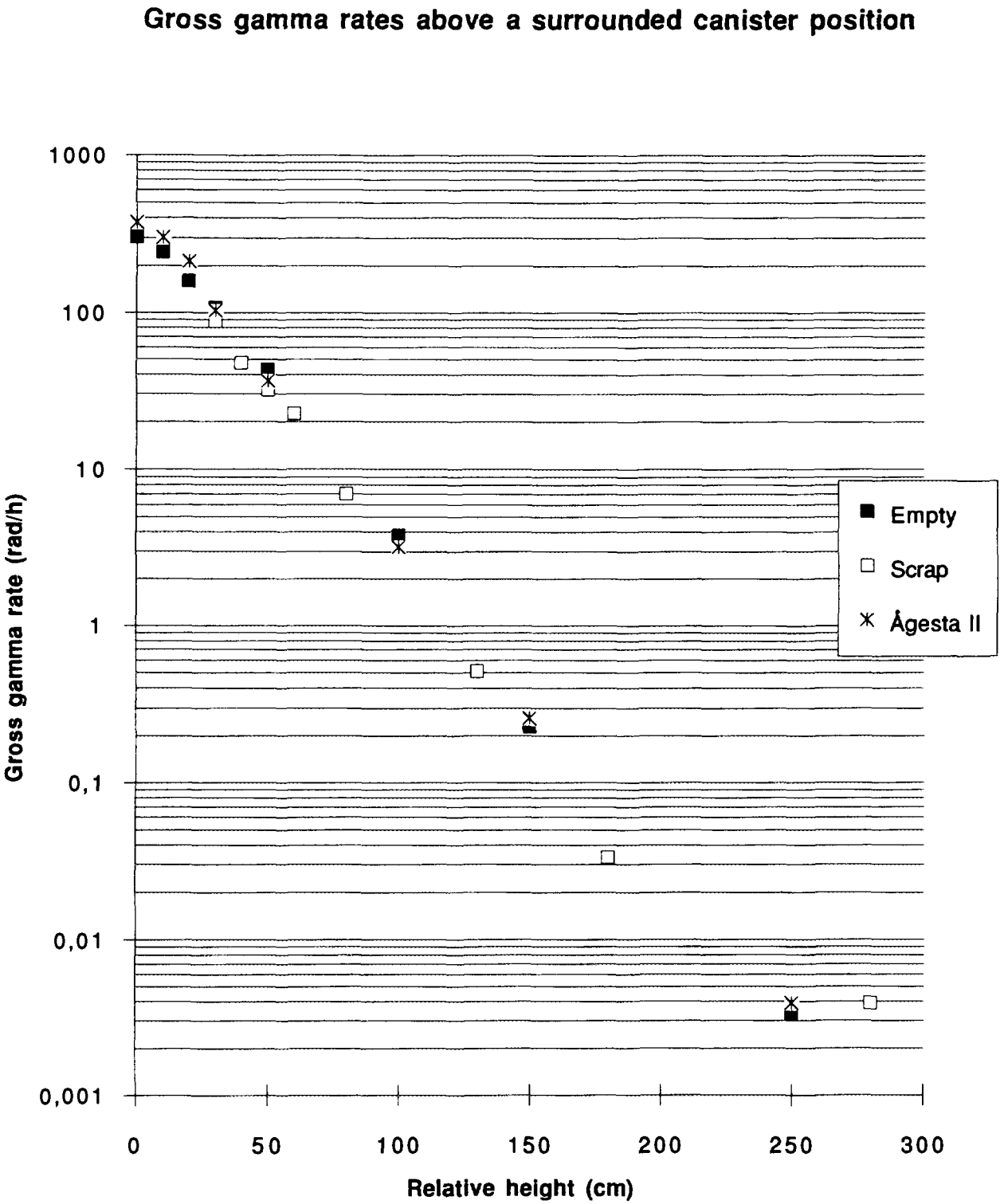


Figure 12. Gross gamma rates as a function of relative collimator height at an empty canister position surrounded by BWR canisters and with the position filled with canister F002. The handle of the Ågesta assembly corresponds to 0 cm.

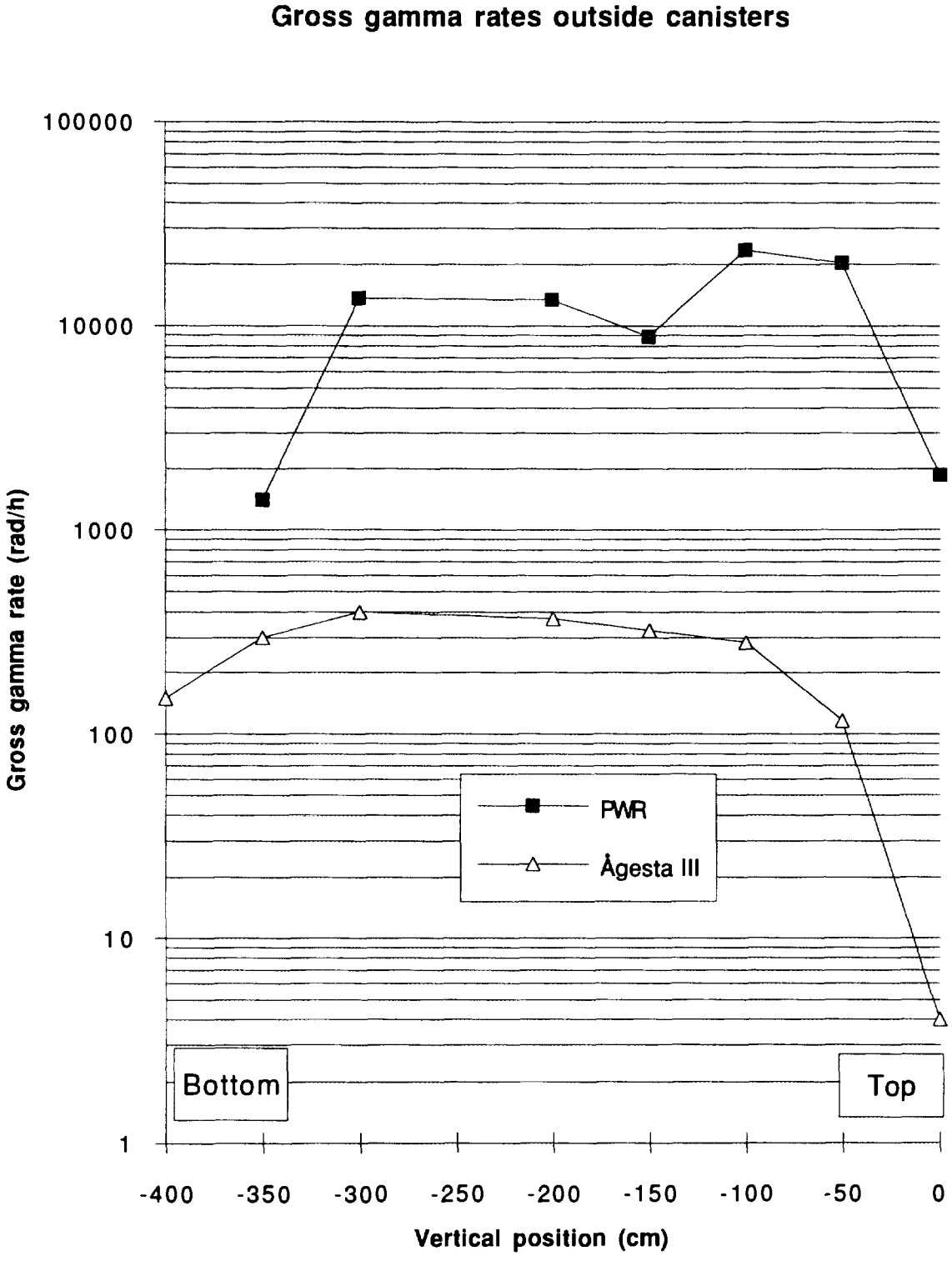


Figure 13. The gross gamma rates outside a PWR and an Ågesta canister.

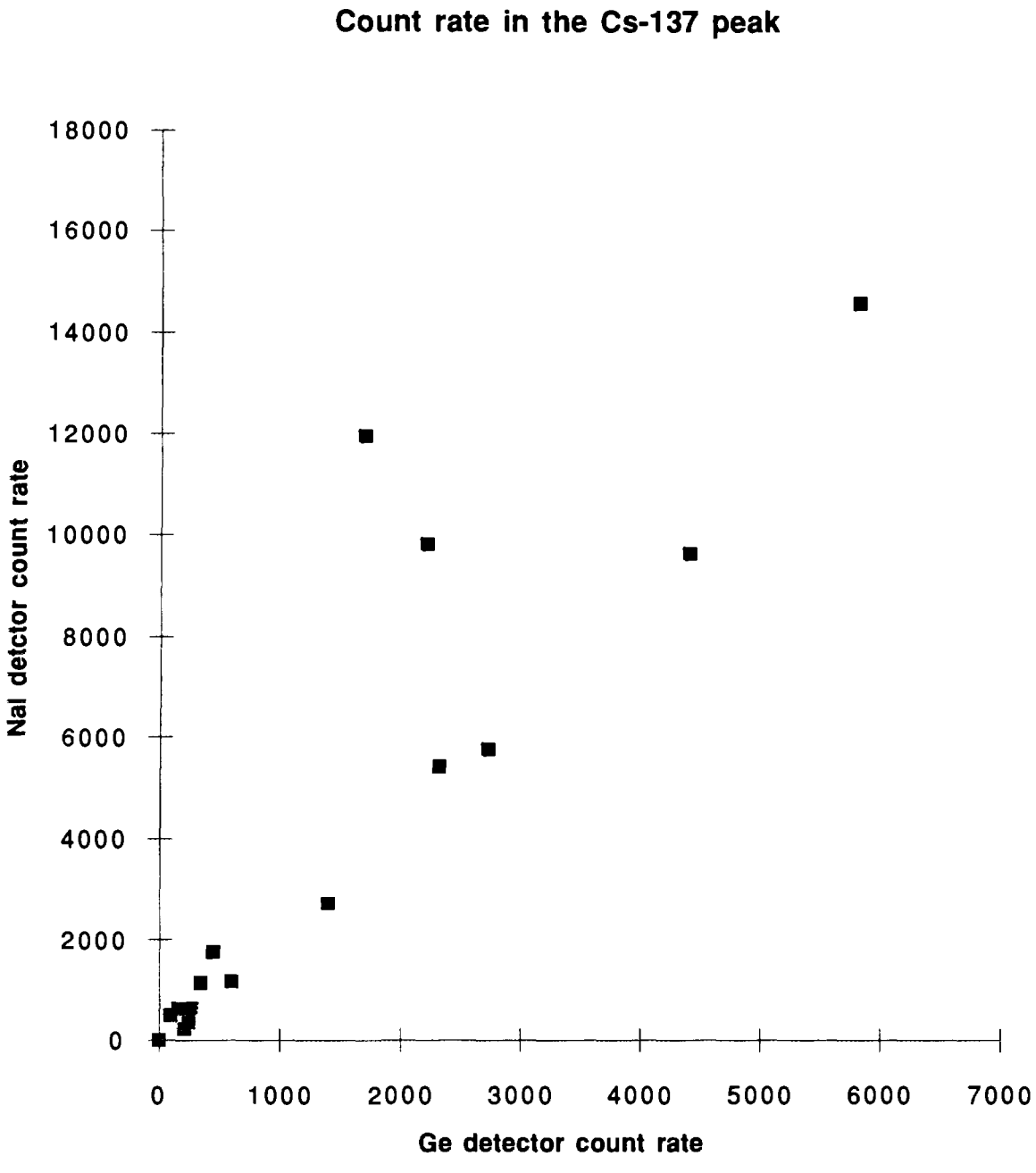


Figure 14. Count rates in the 662 keV peak in the NaI and Ge spectra. The two data points deviating most from the straight line correspond to PWR assemblies 2E2 and 39A.

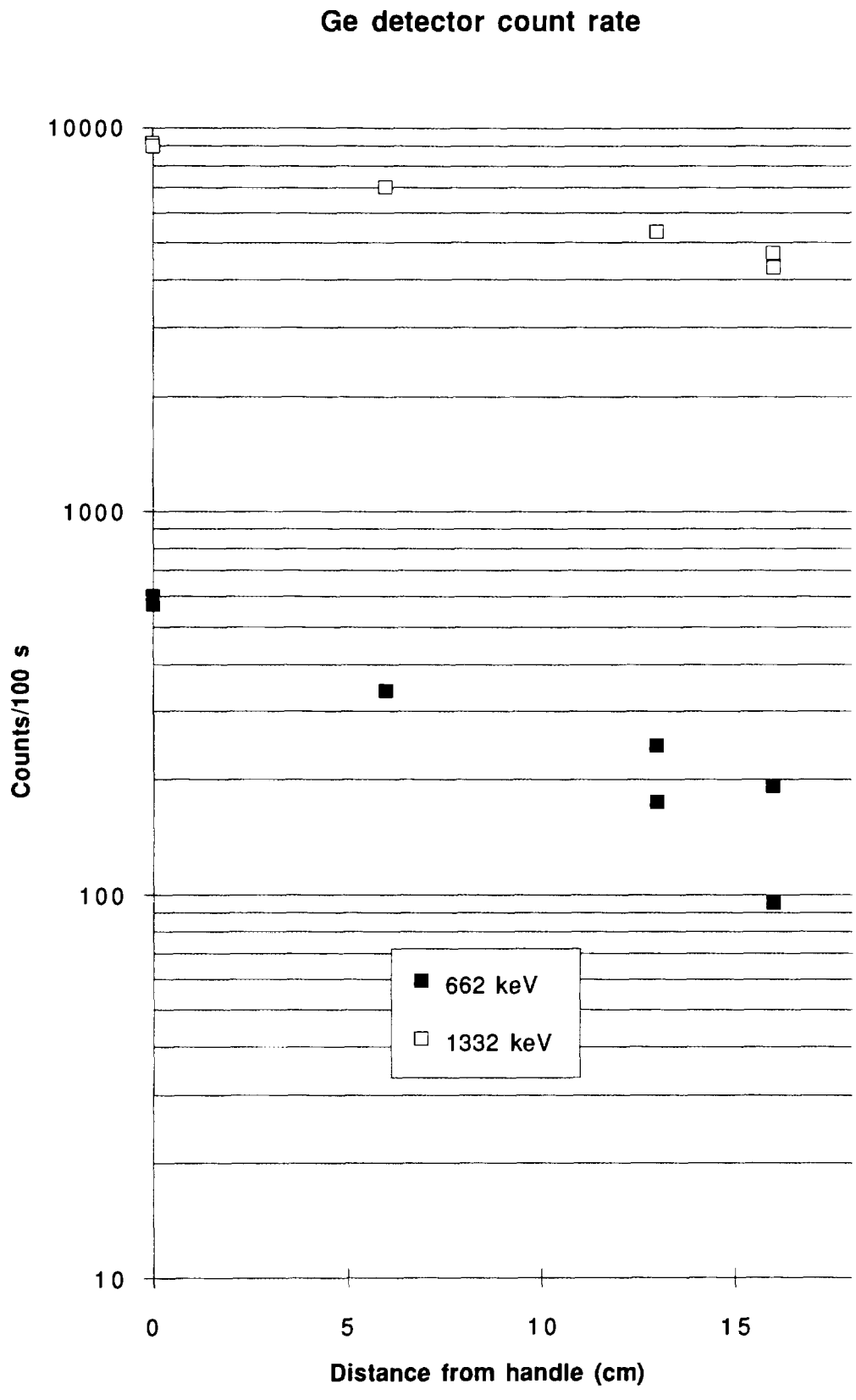
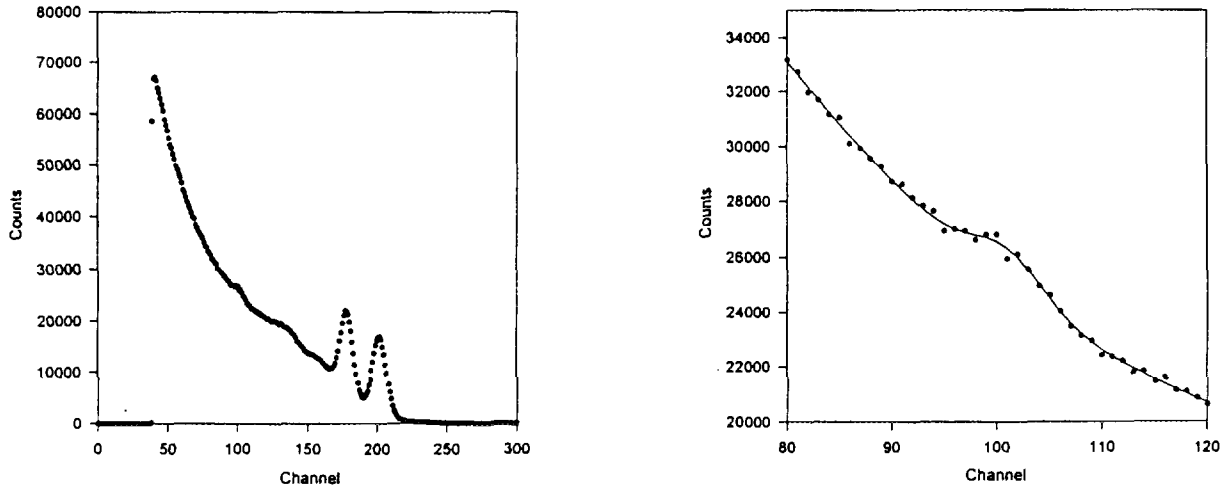


Figure 15. Measured count rates in the HPGe spectra for Ågesta assembly 04-130 as a function of collimator-to-assembly distance.



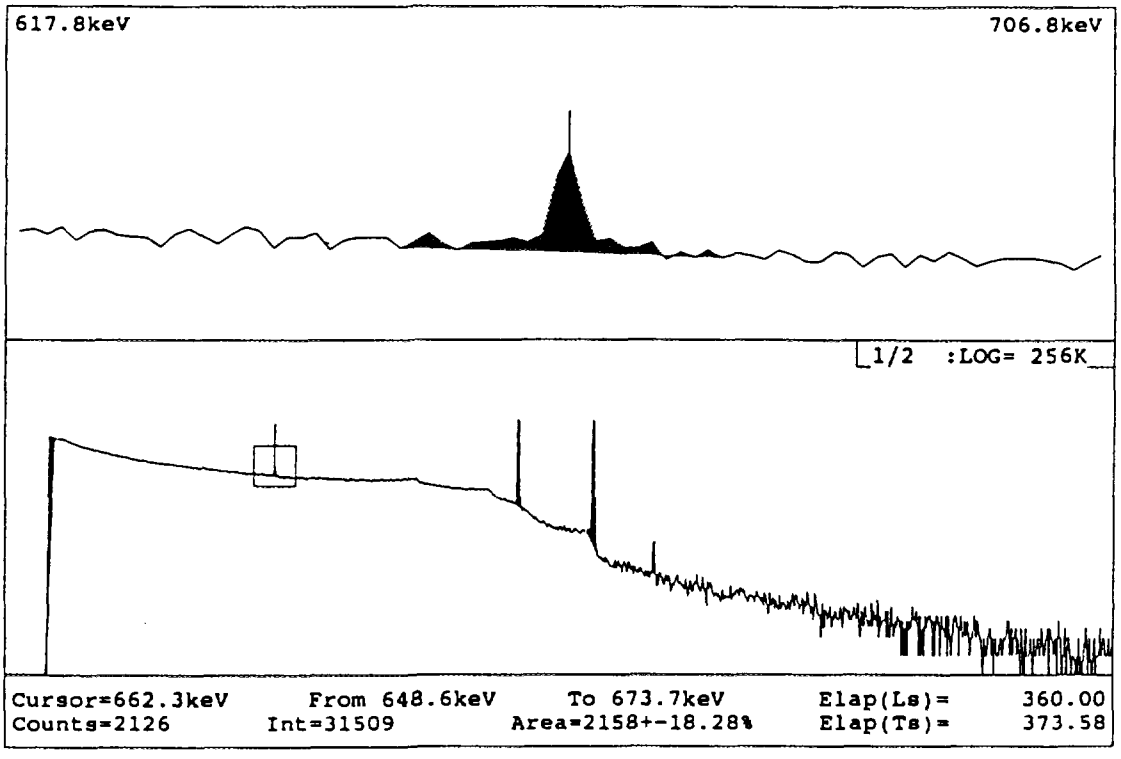


Figure 16. NaI spectrum (top) and Ge spectrum (bottom) of an Ågesta III assembly with a burnup of 8125 MWd/tU and 20 years cooling time. The collimator was positioned at the level of the handle (measurement 7 in Table 4).

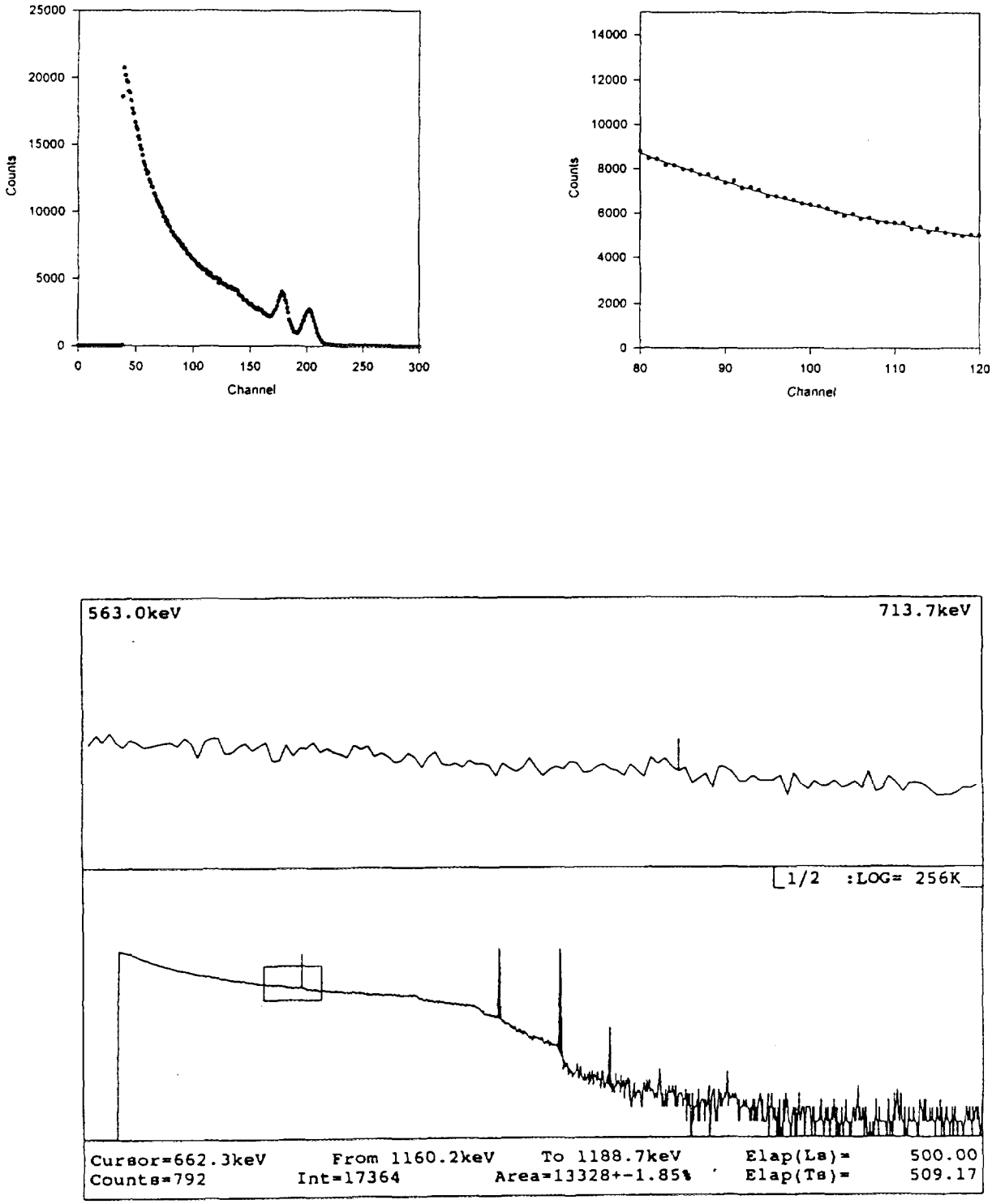
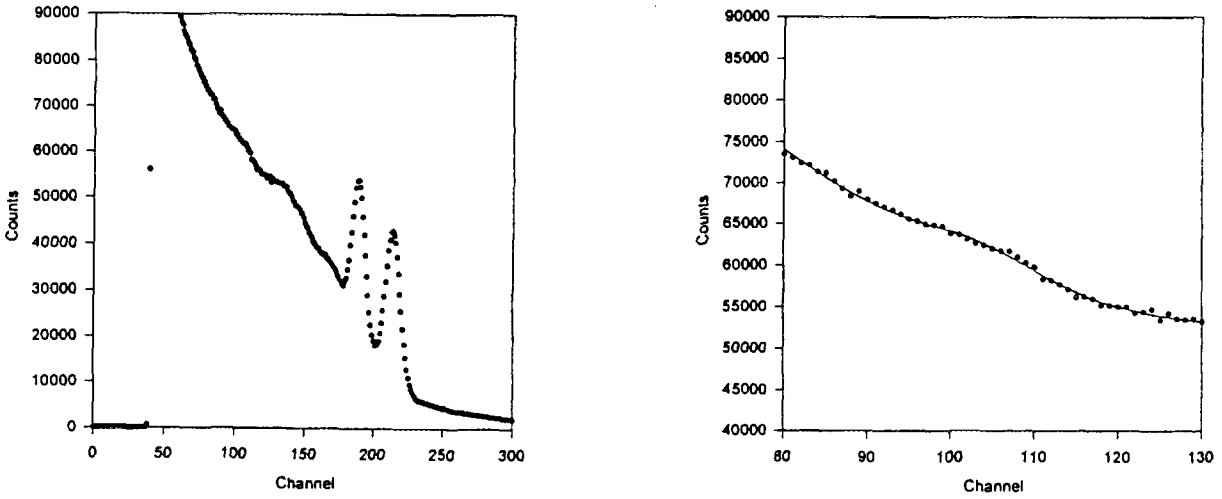


Figure 17. NaI spectrum (top) and Ge spectrum (bottom) taken with the collimator positioned between Ågesta assemblies in canister E006 (measurement 15 in Table 4).



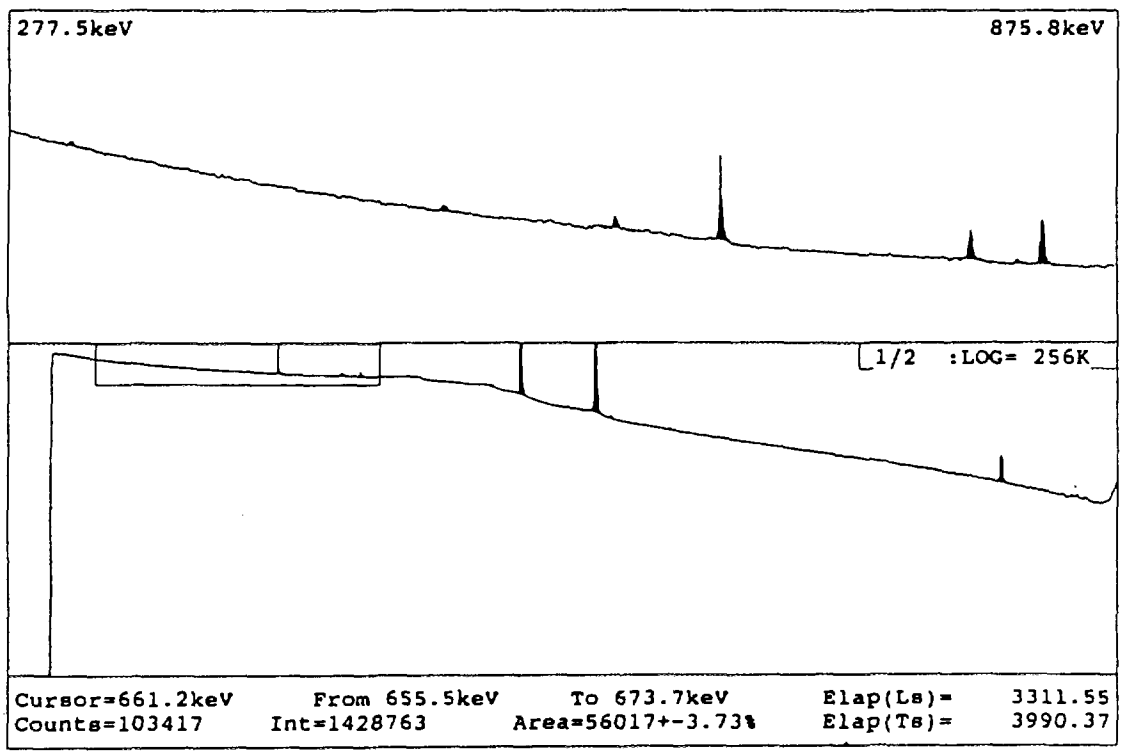


Figure 18. NaI spectrum (top) and Ge spectrum (bottom) from a covered PWR assembly with a burnup of 35869 MWd/tU and 2 years cooling time (measurement 17 in Table 4).

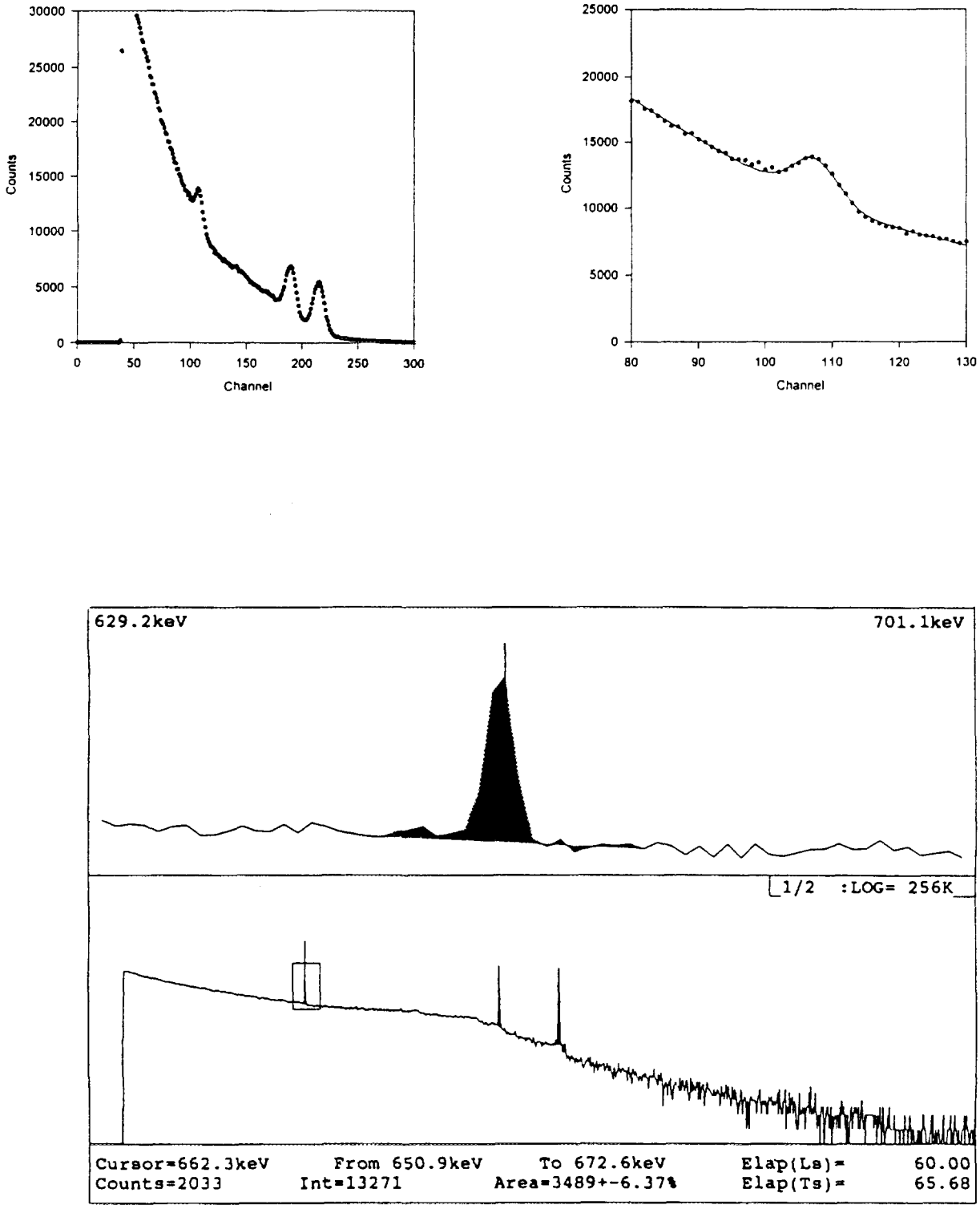


Figure 19. NaI spectrum (top) and Ge spectrum (bottom) from a BWR assembly with a burnup of 23525 MWd/tU and 11 years cooling time (measurement 18 in Table 4).

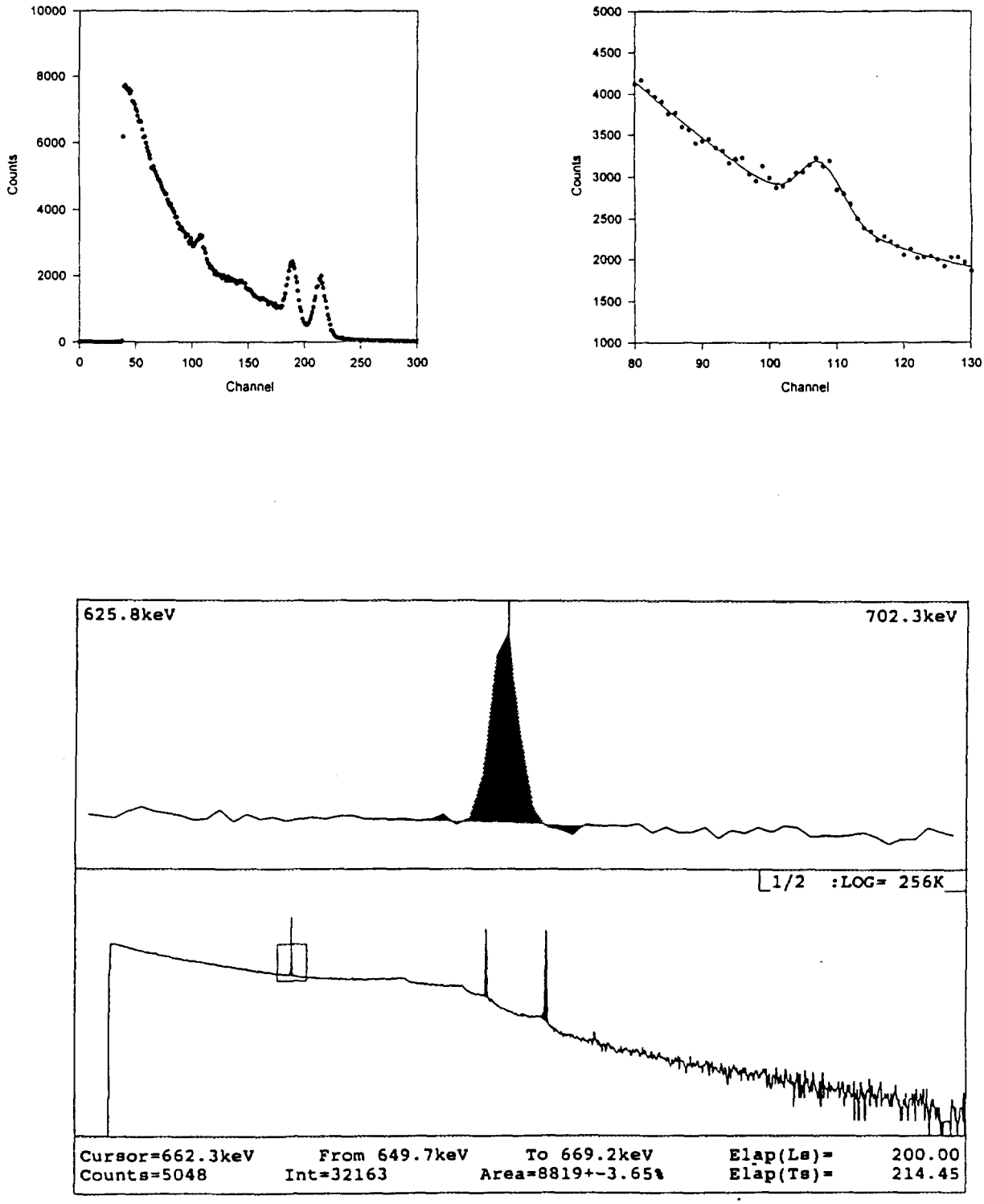


Figure 20. NaI spectrum (top) and Ge spectrum (bottom) from a rod cassette with an average burnup of 7682 MWd/tU and 13 years cooling time (measurement 20 in Table 4).

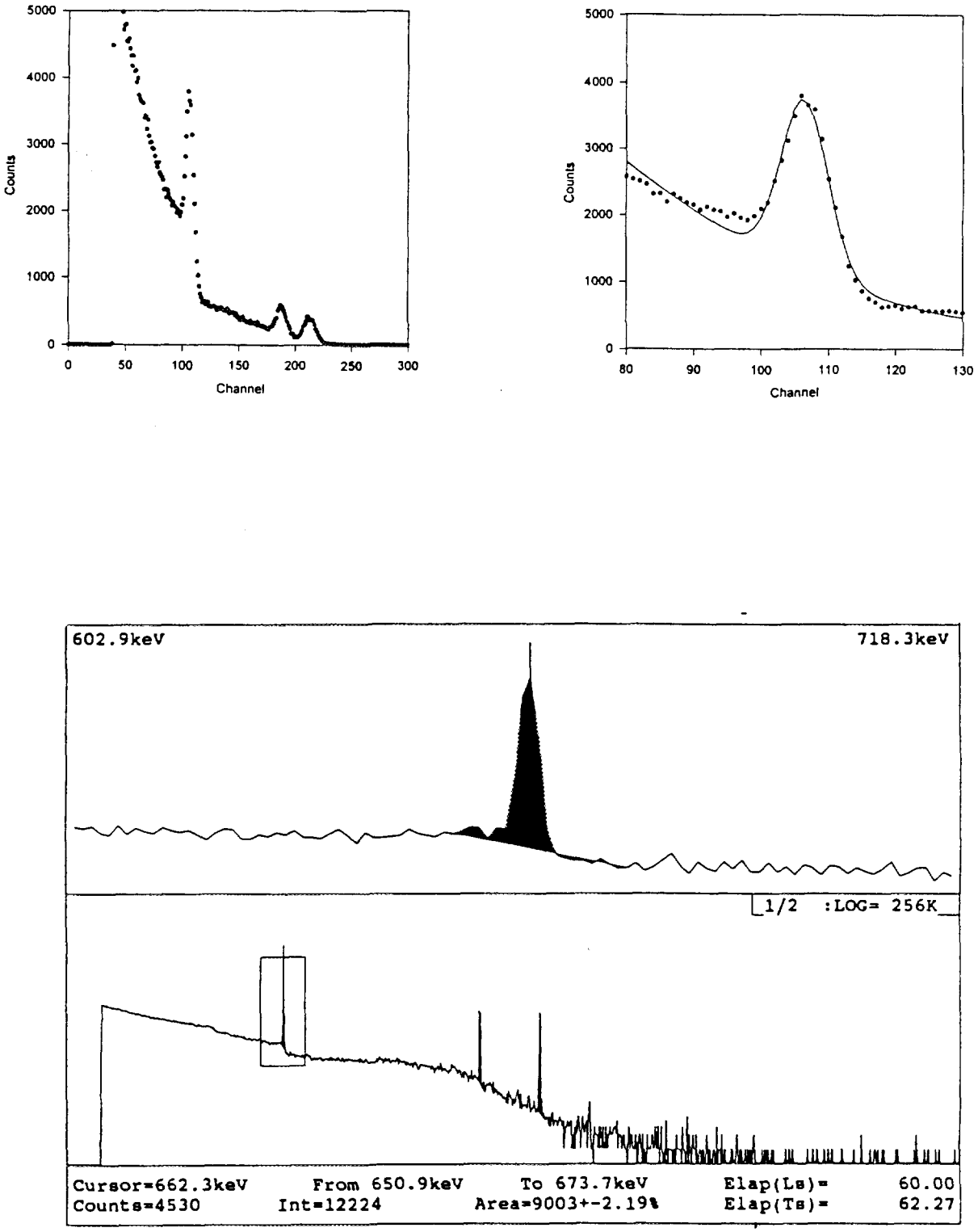
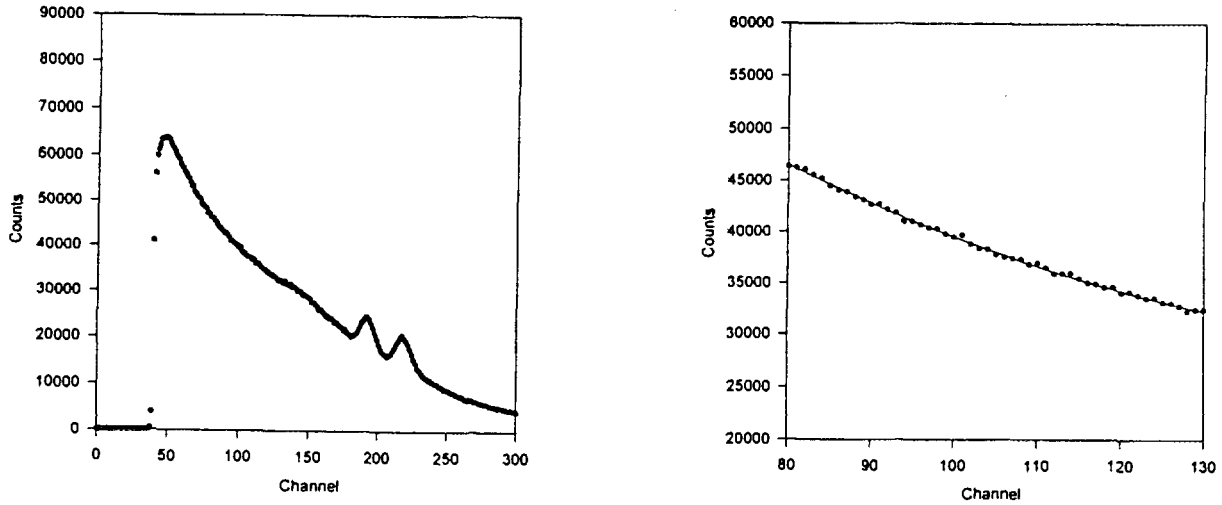


Figure 21. NaI spectrum (top) and Ge spectrum (bottom) from a scrap container with the collimator positioned aside the top plate (measurement 23 in Table 4).



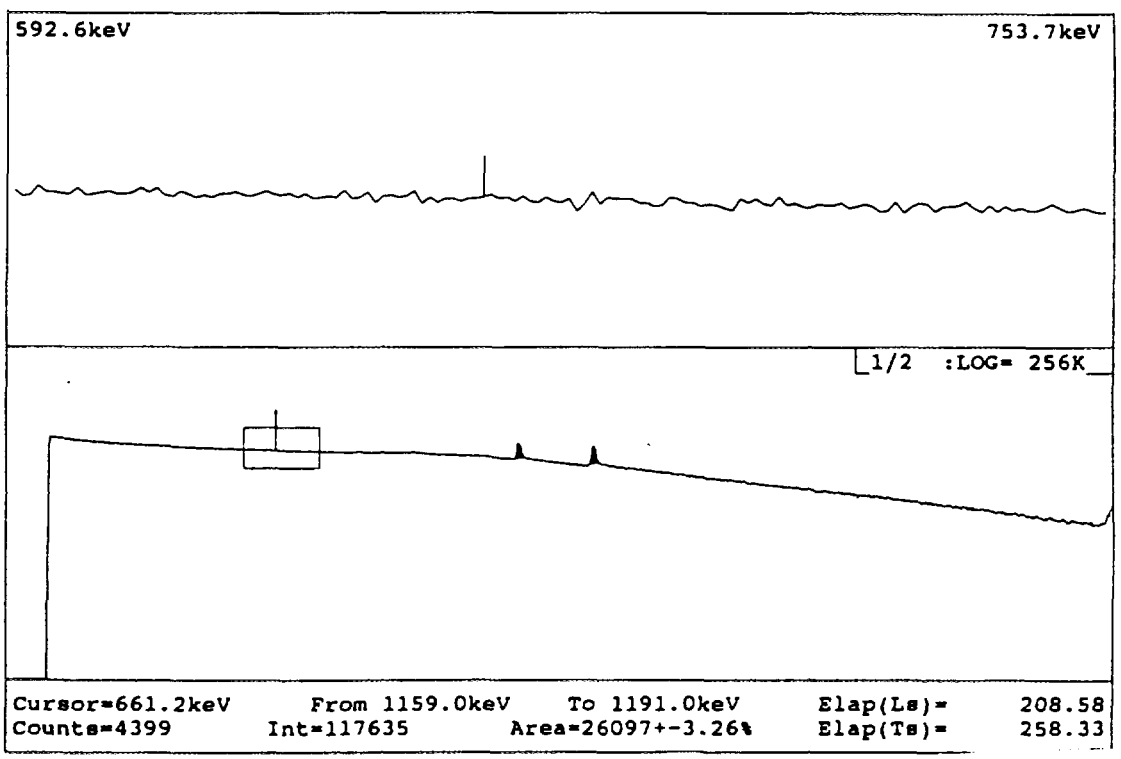


Figure 22. NaI spectrum (top) and Ge spectrum (bottom) from a BWR control rod (measurement 24 in Table 4).

STATENS KÄRNKRAFTINSPEKTION
Swedish Nuclear Power Inspectorate

Postadress/Postal address	Telefon/Telephone	Telefax	Telex
SKI	Nat 08-698 84 00	Nat 08-661 90 86	11961 SWEATOM S
S-106 58 STOCKHOLM	Int +46 8 698 84 00	Int +46 8 661 90 86	