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Manual

High-Temperature Engineering Test Reactor Door Valve Monitor System

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*High-Temperature Engineering Test Reactor
Door Valve Monitor System*

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HIGH-TEMPERATURE ENGINEERING TEST REACTOR DOOR VALVE MONITOR SYSTEM

by

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ABSTRACT

This manual describes the detector design features, performance, and operating characteristics of the High-Temperature Engineering Test Reactor (HTTR) Door Valve Monitor System spent-fuel monitor. The HTTR Door Valve Monitor System (HDVM) is installed in the HTTR door valve to provide unattended monitoring data for the transfer of spent fuel through the door valve on the top of the reactor. The system includes a pair of detectors to provide direction of travel and redundancy. The fission product gamma rays are measured using ion chambers (ICs) and the curium neutrons are measured using shielded ^3He detectors. There are two ICs and one ^3He tube inside each detector package. Gamma-ray and neutron detector (GRAND) electronics supply power to the ICs and ^3He tubes, and the data are collected in the GRAND and the Field Works computer. The system is designed to operate unattended with data pickup by the inspectors on a 90-day period. This manual gives the performance and calibration procedures.

GENERAL

This manual describes the design features and operating characteristics of the High-Temperature Engineering Test Reactor Door Valve Monitor System (HDVM) for spent-fuel discharge. The HDVM will be used by the International Atomic Energy Agency (IAEA) and the Japan Atomic Energy Bureau (JAEB) to verify the time and direction of all spent fuel discharged from the High-Temperature Engineering Test Reactor (HTTR).

The IAEA prepared the user requirements for the HDVM system, and Los Alamos National Laboratory prepared the functional specifications and design of the integrated system including the detector, electronics, and software. The detector packages will be installed at the HTTR by the JAEB and IAEA in early 1998.

The HDVM system includes the following components:

- detector package (2 each)
 - two ICs
 - one ^3He tube
 - one Precission Data Technology (PDT) 110-A amplifier
- electronics cabinet
- GRAND-3 (2 each)–(IAEA property)
- Field Works PC (2 each)–(IAEA property)

**FACILITY FLOOR PLAN
AND USE**

Figure 1 shows a schematic diagram of the HTTR floor area. The HDVM is used on the top of the reactor head as shown by position A in Fig. 1. The discharge of the spent fuel takes place during a period of approximately 200 days and the HDVM will monitor the transfer of spent-fuel elements through the door valve.

FACILITY FLOOR PLAN
AND USE

(cont.)

Fig. 1. Schematic diagram of HTTR floor plan for the reactor room showing the location of the HDVM for the discharge period (Position A) and the operation period (Position B).

When the reactor is in operation, the door valve is sealed and the HDVM is moved to position B as shown in Fig. 1. The HDVM remains in position B for about two years of reactor operation between fuel discharges.

During the two-year period of reactor operation, the HDVM sensors will be disconnected from the electronics, and the spare set of ICs and the ^3He tubes will be connected to the electronics to measure the dose levels inside the inspector's sealed cabinet. The reason for the cable change from the door valve to the spare sensors is to avoid the long cable run between the IAEA cabinet and the door valve storage location as shown in Fig. 1. There could be a possibility of cable damage during the long period that the HDVM is in position B.

**FACILITY FLOOR PLAN
IN USE**

(cont.)

The sensors and electronics are run continuously during the two-year period of reactor operations to verify the operational status of the electronics. Another reason for using the spare sensors in the sealed cabinet is that the cabinet is closer to the reactor core than position B for the door valve. A larger ^3He neutron detector is used inside the cabinet to provide the potential for a reactor power monitor.

The door valve is shown in Fig. 2 where the two HDVM penetrations are on the right-hand side.¹ The two HDVM sensor packages have a center-to-center separation of only 200 mm, so determining the direction of the motion from the timing difference between radiation signals in the two systems will be difficult. Special directional shielding has been designed to give a bigger time difference between the two packages.

Fig. 2. Diagram of the HTTR door valve showing the location of the two HDVM detectors.

DETECTOR DESCRIPTION

Figure 3 shows a diagram of a detector package including the ICs, ^3He tube, and PDT 110-A amplifier.

Fig. 3. Diagram of the HDVM detector package showing the two ICs, the ^3He tube, and the PDT 110-A amplifier (dimensions in mm).

Figure 4 shows the units with the shielding cover removed. The neutron detectors are set in a CH_2 cylinder to fix their positions and to moderate the neutrons. The ^3He tubes have a lead and tungsten shield to decrease the gamma dose. Figure 5 shows a close-up of the tungsten shield, an IC, and a ^3He tube.

DETECTOR DESCRIPTION

(cont.)

Fig. 4. The HDVM detector package.

Fig. 5. The HDVM shielding.

DETECTOR DESCRIPTION

(cont.)

The specifications for the ICs and ^3He tubes are given in Table I. Figure 6 shows a diagram of the long and short ICs.

Table I. Detector Specifications	
IC (3)	LND Model 52133
IC (small) (3)	LND Model 52134
IC bias	-300 V
^3He tubes (3)	RS-P4-0803-103 (MG)
^3He detector bias	1680 V
PDT 110-A	SN 962301
PDT 110-A	SN 962302
PDT 110-A (spare)	SN 962303
^3He tube (long)	RS-P4-0836-201

Fig. 6. Schematic drawings of the long and short ICs.

Both of the ICs count gamma rays from the spent fuel as the fuel is transferred through the door valve. The detector tubes are positioned ~40–50 cm from the center line of the fuel-transfer hole and perpendicular to the axis.

The detectors are designed to measure gamma doses in the range of 0.1 to 10^5 R/h from the fuel elements.

ELECTRICAL CONNECTION

A diagram of the cable connections to the GRAND is shown in Fig. 7. The electronics include the components listed in Table II. The ^3He tubes are connected to PDT-110A preamplifiers as shown in Fig. 3. The detector packages are setup to provide redundancy. The neutron signals from detectors A and B are split after the ground isolation box to go to both GRANDs.

Fig. 7. Diagram of the component wiring in the HDVM electronics cabinet containing two GRANDs, and two Field Works computer.

Receiving both neutron signals into both GRANDs provides added redundancy and time synchronization for the neutron peaks. In general, it is necessary to start both GRANDs at the same time to provide synchronization of gamma peaks.

The neutron signal from detector A that is split to GRAND B should not be used in the data filtering decision in GRAND B. This is to prevent a noisy signal line from being able to take both GRANDs out of the filter mode.

Figure 8 shows a diagram of the detectors and cable connections for detectors A and B.

ELECTRICAL CONNECTION

(cont.)

Fig. 8. Sensor model numbers and wiring diagram for the HDVM.

Table II. HDVM Electronic Components

Field Works Computer A	FW7600, IAEA 9739/027 (SN6249347)
Field Works Computer B	FW7600, IAEA 9739/020 (SN6249346)
GRAND-3	Davidson (SNG3-103) 6392/049
GRAND-3	Davidson (SNG3-104) 6392/050

³He-TUBE HIGH-VOLTAGE PLATEAU

The ³He tubes are from Reuter-Stokes with a diameter of 25 mm and an active length of 76 mm. The fill-pressure of the tubes is 4 atm of ³He plus a CO₂ additive. The aluminum walls of the tube are coated with carbon for radiation resistance.

³He-TUBE HIGH-VOLTAGE PLATEAU (cont.)

The high-voltage (HV) plateau for the HDVM ³He tubes is shown in Fig. 9 where the total counting rate is plotted as a function of the HV bias on the detector tubes. For the current application of the ³He tubes, we are using the detectors to count neutrons by selecting the HV operating point to be below the gamma pileup region. The correct HV setting will be verified when irradiated fuel is first measured.

ION CHAMBERS

The two longer ICs are LND Model 52133; they are 19 mm in diameter, 127 mm long, and contained in a sealed steel tube with a 25-mm outside diameter. The shorter ICs are LND Model 52134; they are 19 mm in diameter, 76 mm long, and contained in a sealed steel tube with a 25-mm outside diameter. The sensitivity range of the IC is from ~0.1 to 10⁶ R/h.

The IC has a useful gain range of about seven decades when using the automatic gain-range feature. The software for the GRAND will implement the full automatic gain range with rapid response.

Fig. 9. Detector bias plateau for the ³He tube and PDT 110-A amplifier.

CABLE CONNECTIONS

The sensors, the HV, and the +5 V are connected to the GRANDs using RG-174 coaxial cables with Lemo connectors. Each detector package has six cable connections as shown in Fig. 10. Table III gives the Lemo connector type and number.

The detector assemblies are each connected to the GRANDs.

Fig. 10. Diagram of Lemo connector locations on the end of the HDVM detector package.

Table III. Cables and Lemo Connector Types		
Type	Number	Size
FFA00•250•CLAC 27	4	small
FFA0E•250•CLAC 30	2	large
RG-174 Coaxial Cable	50 m	~3 mm

CABLE CONNECTIONS

(cont.)

The GRANDs are labeled GRAND A and GRAND B. The IC cables from detector A connect to GRAND A. The IC cables from detector B connect to GRAND B.

The general wiring scheme is shown in the HDVM-wiring block diagrams (see Fig. 7 and Fig. 8).

As the signal and bias cables come into a GRAND, they go through a ground isolation box, which puts an inductor between the ground of the GRAND and the grounds of the detector cables that connect to the detector assembly.

LABELS

The two cable bundles are labeled A and B. The labels are attached to the cables very near the connector of each GRAND. Each cable has either the letter A or B as part of its label. This identifies the detector assembly to which it is connected.

GRAND CONNECTIONS

Figure 11 shows a diagram of the edge view of the GRAND triple neutron counter (TNC), IC personality boards, and the connectors on them. Table IV lists the labels on cable A, the board to which it attaches, and the connector on the board.

Fig. 11. The edge view of the GRAND TNC and IC personality boards and the connectors on them.

GRAND CONNECTIONS

(cont.)

Table IV. Cable Connections and Labels for Detector A		
Cable	GRAND Board	GRAND Connector
^3He sig A	TNC	A
^3He HV	TNC	HV
+5 V	Side Panel	9 Pin Connector "D"
IC (long) A	IC	SIG-1
IC (short) A	IC	SIG-2
IC (-300 V) A	IC	Bias

The coaxial cables (RG-174) that connect the sensors to the GRANDs are approximately 50 m long. The components were tested with 50-m-long cables before installation.

AMPLIFIERS

The two ^3He tubes have their PDT 110-A amplifiers inside the sealed detector. The gain in the PDT 110-A amplifiers was preset prior to installation. The ^3He detector bias in the GRAND will be adjusted at the time of spent-fuel transfer to provide the desired sensitivity level. The HV was initially set at 1680 V.

PERFORMANCE CHARACTERISTICS

^3He TUBE TESTS

Prior to installation, the performance of the ^3He tubes and the ICs was measured at Los Alamos using a gamma-ray source and a ^{252}Cf neutron source. The cable between the detector package and the GRAND was 50 m long to check for possible attenuation of the signals.

A ^{252}Cf neutron source was used to measure the HV plateau shown in Fig. 9. The normal operating HV for neutron counting is approximately 1680 V.

We performed measurements in the Los Alamos hot cell using a ^{226}Ra gamma-ray source. The ^{226}Ra source has a dose level of ~ 1500 R/h on contact so it provides a reasonable simulation of the low-intensity spent-fuel components. We positioned the ^{226}Ra source at 10 cm from the side of the detector package. Figure 12 shows the gamma-ray pileup data rate as a function of the ^3He detector's bias. The pileup was observable above 1700 V and we set the initial operating HV at 1680 V. The calculated dose at the ^3He tube during fuel transfer was less than 1 R/h.

Fig. 12. The gamma-ray pileup data rate as a function of the ^3He detector's bias.

^3He TUBE TESTS

(cont.)

The two ^3He tubes are separated by ~20 cm in the two detector packages (see Fig. 2) to provide data on the direction of motion and speed of the spent-fuel-rod transfers. Measurements using a neutron source were performed at Los Alamos to determine the spatial resolution of the pair of ^3He tubes. Figure 13 shows the measured response profiles for the tubes when a neutron source was moved on an axis that was separated by 20 cm from the front of the detector package.

Fig. 13. The measured response profile for the tubes when a neutron source was moved on an axis that was separated by 20 cm from the center line of the detector package.

The multiple peaks in the profiles are caused by the iron and tungsten shielding directly in front of the ^3He tube. The offset in the initial rise of the response functions is used to get the speed and direction of motion. When the detectors are positioned in the steel body of the HDVM, the multiple peaks will go away.

IC TESTS

The two ICs are used for measuring the relative gamma-ray dose. The short IC is near the sample as shown in Fig. 3, and the long IC is shielded by about 20 cm of steel and tungsten. Thus, the short IC will be several orders of magnitude more sensitive than the long IC. The IC response is proportional to the gamma source strength. Table V and Fig. 14 shows the IC response as a function of distance from the 1500 R/h ^{226}Ra source at Los Alamos. At the design-basis distance of 20 cm, the IC sensitivity is several orders of magnitude above the background noise level. The two ICs in each detector package are used to provide redundant data on the direction of motion and speed of the fuel-rod transfers.

Table V. Ion Chamber Calibration Using Ra Source			
Separation Distance (cm)	Short IC Dose (R/h)	Short IC counts/s	Long IC counts/s
19	60	15.0	0.46
12.7	100	30.9	0.49
9.7	140	45.7	0.50
8.2	190	62.1	0.53

IC TESTS

(cont.)

Fig. 14. The IC gamma response vs dose from a 1500 R/h contact gamma-ray source.

CALIBRATION

The spent-fuel transfer takes the fuel elements from the reactor location past the HDVM detector package to the storage area. The speed of the spent fuel discharge is ~ 0.83 cm/s. The fuel is in the measurement zone for ~ 140 s. We collect the data in 10-s time bins to provide ~ 14 data points for the transfer from the reactor core to the loading carousal. Detectors A and B are separated by 20 cm so the time difference between the threshold responses in the two systems is ~ 24 s or two 10-s data time bins.

FRESH-FUEL MEASUREMENTS

Test measurements were performed to determine the sensitivity of the HDVM to fresh-fuel transfer. Ten pressurized water reactor (PWR) rods were placed at a distance of 50 cm from the front of the HDVM to determine the sensitivity to the gammas and neutrons from fresh fuel. The gamma results were too small to be recorded and the neutron results are listed in Table VI. The net rate from the neutron emission was less than 0.02 counts/s so there is no possibility of detecting the loading of fresh fuel into the core. After the reactor has gone critical, the background in the HDVM will be much larger than the rate shown in Table VI.

Table VI. Fresh-Fuel Measurements with UO_2 Rods

Sample	Run Time (s)	Channel A (counts/s)	Channel B (counts/s)
Background	2000	0.054	0.028
10 PWR rods (~ 6 kg U at 3.2%)	2000	0.071	0.044
Net neutron signal (distance ~ 50 cm)	2000	0.017	0.016

FUEL-TRANSFER RESULTS

The direction of motion also can be detected by the shape of the IC peaks. The peaks will be asymmetrical because of the unshielded view of the detector as the element is moved toward the top of the HDVM. The discharged fuel blocks are stored in the carousel at the top of the door valve. As the carousel fills up, the background radiation level in the detector packages increases. Detector A is more sensitive than detector B to this background radiation because detector A is closer to the fuel and there is an opening in the tungsten collimator for detector A that looks up into the carousel location. Figure 15 shows the geometry and shielding for the two detectors. Detector B has tungsten shielding and open collimation in the direction of the reactor core. The shielding configuration shown in Fig. 15 gives the maximum time difference between detectors A and B to establish direction of motion.

Fig. 15. HDVM detector geometry showing the asymmetric shielding for detectors A and B to provide direction of motion data.

REACTOR BACKGROUND MEASUREMENTS

A long (92-cm) ^3He tube is supplied with the system to measure the neutron background during the periods when the reactor is in operation. During this period, the door valve is moved from the reactor core to the storage location shown in Fig. 1 (Position B). The cables to the HDVM are disconnected and reconnected to the spare tubes that are located inside the sealed HDVM cabinet.

Figure 16 shows the HV plateau for the long ^3He tube that is inside the IAEA's electronics cabinet. To increase the counting efficiency, the ^3He tube is inside an ~1.5-cm-thick CH_2 moderator. The two spare ICs also are attached to the GRAND A cable bundle.

Fig. 16. Detector bias plateau for the long (92-cm) ^3He tube that is mounted inside the IAEA's electronics cabinet.

The purpose of the connection to the spare detectors is to provide the IAEA with data that show the status of the equipment during the long period between spent-fuel discharges. To reduce the data storage and review requirements, the data collection frequency could be set to about 1000-s intervals during this period.

CALIBRATION PROCEDURES

The normal transfer of spent fuel is from the reactor core, through the door valve into the fuel transfer machine located on top of the door valve. The HDVM is positioned in the

CALIBRATION PROCEDURES

(cont.)

collimated for the spent fuel gamma-rays than is detector A. There is tungsten shielding on the nose of detectors A and B so that the short IC in B is collimated downward and the short IC in A is collimated upward as illustrated in Fig. 15. The purpose of the local tungsten shielding is to provide data time patterns that are specific to the direction of the fuel transfer.

DIRECTION OF MOTION ANALYSIS

The direction of motion can be determined using the time offsets between detector A and B in the data profiles or by using the shape of the transfer patterns. The offset and pattern information is available for all of the sensors giving three time offsets and six patterns. The most distinctive offset and pattern information is expected to come from the short ICs in the nose of the detectors because of the directional collimation shown in Fig. 15. The performance of the ICs could not be tested until the spent fuel is transferred because an intense gamma source was not available.

NEUTRON TRANSFER PATTERN

The neutron response profile was measured at the time of the installation and acceptance testing at the HTTR facility on January 26-29, 1998.

A spent fuel assembly transfer was simulated at the HTTR by an AmBe source that had an exterior shield with dimensions similar to a graphite fuel block. The neutron source shield had a height of 365 mm and a diameter of 210 mm with a neutron yield of $\sim 10^7$ n/s. Approximately 2×10^6 n/s leaked through the polyethylene shielding.

This AmBe source was scanned through the HDVM using 10-cm steps to obtain the vertical profile shown in Fig. 17. The bottom detector A responds first as the source was transferred upward through the HDVM. The offset in curves A and B is approximately 20 cm on the left side of the peak. For the normal transfer speed of ~ 0.8 cm/s, this 20-cm offset represents ~ 20 s of time offset in the graphical

NEUTRON TRANSFER PATTERN

(cont.)

display of the peaks. As the neutron source moves above the detectors, the neutrons scatter into detectors A and B from the walls and the lower iron shielding in the door valve. This scattering results in an increase in the neutron counts in the detector B. Thus the offset in the response profiles for detectors A and B is only about 5 cm for the curves on the right side of Fig. 17.

As the fuel blocks are deposited into the carousel of the transfer machine, the background in both detectors will increase. Each additional fuel block will raise the background in a step fashion as illustrated in Fig. 18. If the fuel is moved downward through the HDVM, the step pattern is reversed in time.

Fig. 17. Neutron rates vs position for the AmBe source scanned through the HDVM in 10-cm steps from bottom to top.

NEUTRON TRANSFER PATTERN

(cont.)

Fig. 18. Conceptual diagram of fuel transfer from the reactor core to carousel with a long interval (~ 1 h) between transfers.

The present data from the AmBe neutron source transfer shows the asymmetric direction of motion pattern.

To evaluate the neutron transfer pattern using continuous motion and software data collection, the AmBe source was moved through the detectors at a speed of about 1 cm/s. The detection time bin in the GRAND was set at 2 s in the nonfilter mode. The source was transferred from 160 cm above the detectors-center line to 160 cm below the detectors. The direction of the crane was then reversed to pull the source up through the HDVM to provide data for both directions of motion. The transfer data pattern is shown in Fig. 19 and the asymmetric neutron pattern shows the direction of travel. The neutron rate at the top position is about a factor of 5 higher than the rate at the bottom position in detector A. The times in detectors A and B were not synchronized for the tests.

NEUTRON TRANSFER PATTERN

(cont.)

Fig. 19. Continuous neutron data collection with 2-s time bins for the AmBe source scanned from above (+160 cm) the HDVM to below the HDVM (-160 cm) and then returned to the top position.

Fig. 20. Logarithmic display of the continuous neutron data scan from above (+160 cm) to below (-160 cm) the HDVM and then returned to the top position.

If we display the neutron transfer pattern with a logarithmic display as shown in Fig. 20, we see that the shapes of the profile wings are different for the neutron source above the HDVM compared with the source below the HDVM. When the source is above the HDVM, there is a streaming of scattered neutrons into both detectors, giving an elevated neutron rate. Thus the shape of the neutron profile gives the direction of motion.

GAMMA-RAY PATTERNS

The direction of motion can also be determined from the shape of the gamma-ray profiles. The gamma profiles are expected to be sharper because of the directional collimated shielding. The short detector A is collimated to look directly upward as illustrated in Fig. 15 so that the fuel in the transfer machine carousel will give a significant background rate in detector A. Thus as the carousel fills up, the background data in detector A will increase with the step pattern shown in Fig. 18. On the other hand, if the fuel transfer direction is reversed, the step pattern is reversed.

The primary indicator of the direction of motion is the shape of the gamma-ray profile. The fuel blocks below the detectors are shielded by the thick iron ledge on the bottom of the door valve. As the fuel is pulled above this ledge, the gamma rate will increase rapidly reaching a maximum value when the block is directly in front of the detectors. As the fuel block moves above the detectors, the IC rate will decrease slowly because of the upward-directed collimation in the short IC in detector A.

The gamma-ray profiles could not be measured at the January 1998 installation of the HDVM. However, Fig. 21 shows a conceptual diagram of the response profiles for the short ICs in detectors A and B. Both the time offsets of the peaks and the asymmetric shapes can be used to determine the direction of transfer. Detector A will have a higher peak value than detector B because A has a wider collimation to view the fuel block.

GAMMA-RAY PATTERNS

(cont.)

Fig. 21. Conceptual diagram of gamma-ray profiles for detectors A and B with a spent fuel assembly transferred from the core area to the carousel area.

FINAL CALIBRATION
FOR SPENT FUEL

The final calibration of the HDVM must wait until the irradiated fuel transfers in about three years. The procedures for this activity follow.

1. After the operator has transferred the door valve to the top of the reactor vessel, remove cables from the IAEA cabinet and attach to detector packages A and B in the HDVM.

FINAL CALIBRATION
FOR SPENT FUEL

(cont.)

Fig. 22. Diagram to define the position of the ^{252}Cf calibration source to check the performance of the HDVM.

2. Place a small IAEA ^{252}Cf calibration source ($\sim 10^4$ – 10^5) on the outside of the HDVM directly between the exterior flanges of detectors A and B as shown in Fig. 22. In this source position, the two neutron detectors should give approximately equal counting rates.
3. Collect the ^{252}Cf source data with the software in the data collection mode to verify that the software is functioning properly.

A ^{252}Cf calibration source of 1.32×10^4 n/s should give a count rate of ~ 20 counts/s. Figure 23 shows the data from the HDVM installation where the source yield was 1.32×10^4 n/s and the data was collected for ~ 5 min.

FINAL CALIBRATION
FOR SPENT FUEL

(cont.)

Fig. 23. Neutron data from ^{252}Cf test source placed on the face of the HDVM as shown in Fig. 22.

4. Change the GRAND setup parameters to 5-s time bins and nonfilter mode to collect the initial calibration data. This is to give better response peak resolution than for 10-s bins and to reduce the filter vs nonfilter wait times.
5. Observe that the background rates in all six sensors are at levels that are somewhat higher than at the floor storage position. The matching neutron and gamma sensors in detectors A and B should have about the same background rates. When the door valve is on the floor away from the reactor, the neutron background rates are ~ 0.5 cps and the gamma backgrounds units are ~ 0.001 . The neutron counts from the ^{252}Cf check source will increase the gamma rates to ~ 0.0025 because of cross-talk in the wiring. When the HDVM is on top of the reactor vessel, both the neutron and gamma background are expected to increase significantly. The low-level background data must be copied on a disk and viewed in the RADIATION REVIEW software.

**FINAL CALIBRATION
FOR SPENT FUEL**

(cont.)

6. Synchronize the start of the two GRANDs (see step 14) and set the software in the data collection mode for at least 5 min prior to fuel transfer. Have the facility operator transfer a typical spent fuel block at the normal transfer speed. The operator should release the fuel block in the carousel above the door valve. Continue to collect data for additional fuel transfers if practical.
7. If the time between transfers is more than about one hour, copy the data file for the first transfer for review on a separate computer. Restart the data collection of the background rates from the reactor core and the fuel assembly in the carousel.
8. Collect data for all fuel transfers during the calibration period. Continue to collect background rates between and during the fuel transfers to obtain data profiles similar to Figs. 18 and 19.
9. If it is practical, have the operator transfer a fuel block from the carousel area back into the reactor core area. Then return the fuel block to the carousel.
10. During the calibration period, collect data continuously with only small interruptions for copying data.
11. Collect background data during the transfer of the fuel loading machine from the reactor core to the floor spent-fuel storage area.
12. Collect data for the transfer of any reactor components, such as shields and plugs, through the HDVM.
13. The calibration is expected to be part of the normal spent fuel discharge except for the one fuel block reverse travel that is optional.
14. As part of the GRAND parameter verification, the inspector needs to verify that date and time of both GRANDs (GRNDUP-A and GRNDDN-B) are synchronized. This is accomplished by the following procedures.
 - a. If data are currently being taken, press the END button on both GRANDs.
 - b. Press the Setup button on both GRANDs.

**FINAL CALIBRATION
FOR SPENT FUEL**

(cont.)

- c. Press the down arrow until the date and time setting screen is displayed on both GRANDs.
- d. Enter the SAME date and time on both GRANDs up to pressing enter on the seconds. (Do NOT press enter on the seconds. At the exact time you press the enter button on the seconds, the GRAND will set the specified date and time. This will be done on both GRANDs to be sure the date and time is synchronized between both GRANDs).
- e. At the same time, press the enter button on both GRANDs. At the exact time you press the enter button on the seconds, the GRAND will set the specified date and time. This is done on both GRANDs to be sure the date and time is synchronized between both GRANDs.

DATA EVALUATION

The signal rates from the spent fuel transfer will be large and variable. Because the fuel discharge takes place within a few weeks or months from the reactor shut down, the fission product gamma rays will be decreasing with a rate that is inversely proportional to the cooling time. Thus, fuel discharged at one month after shut down would have a gamma rate that is about twice as large as fuel with a cooling time of ~3 months. The neutron emission will be coming from ^{242}Cm and ^{244}Cm with decay half-lives of 163 d and 18.1 yr, respectively. Thus, there will be a slow reduction in the neutron rates as a function of time. The neutron backgrounds from the fuel elements stored temporarily in the carousel will build up in a stepwise mode as illustrated in Fig. 18. When the carousel is full, it is moved from the reactor vessel to the floor storage position for unloading the fuel. The data should show a drop in the backgrounds as the HDVM is closed and the transfer machine is moved to the floor position.

EVALUATION SUMMARY

The primary function of the HDVM is to measure the neutron and gamma rates of the fuel blocks to verify that the fission products and curium are consistent with spent fuel. The number of transfers and direction of transfers can be verified in the unattended mode. The direction of transfer can be determined from both the time shifts and the data patterns. Transfer of irradiated material other than fuel assemblies can be detected if the emitted radiation levels are not less than a few percent of the spent fuel blocks. The AmBe neutron

EVALUATION SUMMARY

(cont.)

calibration source had an emission rate that was a factor of ~ 2 less than the rate expected from a fuel block. Thus, the peak neutron counting rate for the spent fuel is expected to be ~ 1000 counts/s. This rate is three orders of magnitude above the ambient background level. However, the spent fuel carousel could be expected to raise the background level to about 10% of the peak level in the spent fuel transfer profile. The neutron background from the carousel should provide a count of the number of fuel blocks in the carousel as illustrated in Fig. 18. The gamma-ray background noise level is equivalent to about 40 mR/h (400 μ Sv/h) and the spent fuel will emit $\sim 10^5$ R/h. Thus, the signal level is more than six orders of magnitude above the room background. However, when the door valve is placed on the reactor vessel and fuel is stored in the carousel, the backgrounds will increase by several orders of magnitude. We might expect the gamma-ray transfer peak to be approximately two orders of magnitude above the backgrounds from the core and carousel.

**PROCEDURES FOR USE
DURING BACKGROUND
PERIOD**

For the ~3-yr period when the reactor is in operation and the HDVM is on the floor, the following procedures apply.

1. During the IAEA periodic visits, remove the cabinet seals and collect the data on a disk using the standard IAEA procedures for UFFMs.
2. The GRNDUP-A has room background data from the long ^3He tube and GRNDDN-B is turned off. Thus, only collect data from the system A computer.
3. Verify that system A is functioning properly with respect to filtering and data file size.
4. The room background for the long (91-cm) ^3He tube was 3.0 counts/s at the time of installation. If there is an unexplained major decrease or increase in this rate, a ^{252}Cf test source can be placed in contact with the tubes CH_2 moderator (50 x 50 x 95 mm) near the center of the tube. The counting rate under this condition was 150 counts/s for a ^{252}Cf source yield of 1.32×10^4 n/s at the time of installation.
5. The setup parameters in the GRANDs at the time of installation are given in Table VII.
6. Restart GRNDUP-A and verify that it is working. GRNDDN-B and the corresponding PC should remain off.
7. Reseal the cabinet and review the data offline using Radiation Review software.

**PROCEDURES FOR USE
DURING BACKGROUND PERIOD**

(cont.)

Table VII. HTTR DVM Parameters - Final parameters after installation on 1/29/98		
Key/Parameter	HTTR GRNDUP-A Value	HTTR GRNDN-B Value
OFFSET/Offset Disconnect	INTERNAL	INTERNAL
NEUT/Neutron Inputs	EXT A, EXT B, EXT C	EXT A, EXDT B, EXT C
GAMMA/mode/gain (if manual)	AUTO, AUTO	AUTO, AUTO
SETUP/Acquisition mode	NEUTRON & GAMMA	NEUTRON & GAMMA
SETUP/baud rate/parity	9600, 7+EVEN	9600, 7+EVEN
USER/count time	10 s	10 s
USER/filtered point	AVERAGE	AVERAGE
USER/neutron channels used	A=YES, B=NO, C=NO	A=YES, B=NO, C=NO
USER/gamma channels used	G1=YES, G2=YES	G1=YES, G2=YES
USER/no filter runs and sigma	3 runs, 3.0 sigma	3 runs, 3.0 sigma
USER/hours between offset	168, 192 MAX	168, 192 MAX
USER/minutes between battery checks	15	15
USER/neutron thresholds	A=10, B=5000, C=5000	A=10, B=5000, C=5000
USER/gamma thresholds	G1=10.0, G2=10.0	G1=10.0, G2=10.0
USER/filtering	FILTER DATA	FILTER DATA
USER/neutron filter limit	1c/s, 1c/s, 1c/s	1c/s, 1c/s, 1c/s
USER/gamma filter limit	0.1, 0.1	0.1, 0.1
USER/gamma multiplier	0.010	0.010
USER/exit MII runs	10	10
USER/enter MII runs/threshold	3 runs, 1.5 threshold	3 runs, 1.5 threshold
USER/save buffers	first 50 of last 70	first 50 of last 70
USER/local background	first 25 of last 30	first 25 of last 30
USER/trigger condition	THRESHOLD ONLY	THRESHOLD ONLY
USER/syn time	NO, 04:30, 2s, 5 m	NO, 04:30, 2s, 5 m
USER/do tamper test	NO	NO
USER/tamper conditions	3.0 sigma, 1800 c/s	3.0 sigma, 1800 c/s
USER/tamper points	50	50

ELECTRICAL CABINET

The GRAND and computers are located in an installed IAEA cabinet with a ground to the building ground. All electronic components are modular commercial items and satisfy standard UL (or equivalent) requirements. If it is necessary to repair the commercial components from the electrical cabinet, the inspector will remove the module and replace it with an identical module. The failed component will be returned to the IAEA's field office or headquarters for repair.

The electrical power for the HDVM will be a constant-voltage-constant-frequency (CVCF) power supply that will be provided by the facility operator. In addition, the IAEA will place a uninterruptible power supply (UPS) inside the cabinet. The supply will give 100-V/50-Hz electrical power that will not be interrupted in the case of line-power failure. This power supply will be grounded to the building electrical ground.

The UL-approved (or equivalent) power cord between the electronics cabinet and the CVCF supply will be grounded to the electrical supply.

All of the electronic modules in the cabinet will use UL-approved cables (or equivalent) with grounds to the power supply.

The electronic components and their position in the cabinet are shown in Fig. 24. These components include the following:

- two Field Works PCs,
- two GRAND-3s,
- one PDT-110A and long ^3He -tube, and
- two ICs.

All of the instrument cases will be grounded to the power supply cable. The modules are not to be opened or serviced in the HTTR facility. In case of component failure, the module will be replaced by a complete spare module. The failed module will be returned to the vendor or sent to the IAEA for servicing. The standard electrical safety procedures at those facilities will be followed during maintenance activities.

The cable runs between the electronics cabinet and the detectors are protected by grounded coaxial cable.

ELECTRICAL CABINET

(cont.)

Fig. 24. HDVM cabinet overview showing two GRAND-3s, two PCs, and the spare ^3He tube that is used as a reactor area power monitor during the period when the HDVM is removed from the reactor-head shield.

REDUNDANCY

Duplicate electronic modules operate in parallel to increase reliability and to avoid data loss in case of component failure. The system is designed with two-fold redundancy. The two ICs and the single ^3He tube are separated by about 20 cm to provide a fuel-rod-passage time signal that indicates the direction of motion.

The detector A signal from a fuel transfer rises rapidly as the element comes through the steel wall of the door valve and falls off more slowly as the fuel rod moves toward the discharge area. This pattern is reversed if the direction of motion is reversed. Thus, the shape of the signal-time trace also provides the direction of motion.

This redundancy in the sensors is important to avoid maintenance activity or loss of data in case a single sensor fails.

REDUNDANCY

(cont.)

The redundancy is only two-fold for the two GRANDs and the two computers; however, they are in the cabinet where modular replacements are possible. The performance of the HDVM system can be monitored by checking the consistency of the six sensors.

If a single sensor fails in either detector package, the system should continue operation with less redundancy. Maintenance in the detector package should not be performed until the loss of redundancy jeopardizes the safeguards application.

The replacement of sensors in the detector packages should only be performed by a maintenance specialist.

REFERENCES

1. Kiyonobu Yamashita, Fujio Miyamoto, Sigeaki Nakagawa, and Toshiyuke Tanaka, "Safeguards Concept for the High Temperature Engineering Test Reactor Using Unattended Fuel Flow Monitor System," *J. Nucl. Mater. Manage.* **XXV** (4), 15-19 (August 1997).

APPENDIX A

**GAMMA-RAY DOSE CALCULATIONS ON THE
OUTSIDE OF HDVM**

Dose Rates Adjacent to the HTTR Door Valve Monitor System

S. Nakagawa and M. E. Abhold

Executive Summary

This memo presents radiation dose calculations for radiation doses adjacent to the Door Valve Monitor System (DVMS) on the Japan Atomic Energy Institute (JAERI) High-Temperature Engineering Test Reactor (HTTR).

Each of the two High-Temperature Engineering Test Reactor Door Valve Monitor System (HDVM) consists of two ion chambers (ICs) and one ^3He tube contained in a hermetically-sealed stainless-steel detector package. Tungsten shielding plugs are also incorporated into the detector package and package lid. The detector packages are to be inserted into two penetrations through the iron door valve. Since each penetration presents a potential path for gamma rays and neutrons to reach the outer surface of the door valve where personnel may be located during unloading operations, calculations were performed to determine if the tungsten plugs will provide adequate radiation shielding.

The results indicate that the shielding included in the detector package is sufficient to meet the HTTR personnel radiation safety criteria.

1.0 Introduction

Two radiation detector packages are to be installed in the HTTR door valve as part of the reactor safeguards system. Each detector package presents a potential streaming path for radiation emitted from the spent fuel to reach the surface of the door valve where personnel may be located. Calculations were performed to determine the adequacy of the radiation shielding incorporated into the detector package.

Estimates of the gamma-ray and neutron dose rate at the surface of the door valve, and at a distance 1 m from the door valve, will be presented. The calculational model accounted for the possibility of a streaming path between the monitor and penetration walls.

2.0 Calculational Methodology

The dose rates to be presented were calculated with the three dimensional Monte Carlo transport code (MCNP), Version 4a for IBM PC compatible computers. The code was obtained from the Los Alamos National Laboratory X-TM group and installed and benchmarked with the Los Alamos suite of 25 benchmark problems on Pentium™ processor PCs. All runs were performed on PC-class machines.

Los Alamos XT-M group-supplied ENDF/B-V continuous energy cross sections were used for all materials.

2.1 Fluence-to-Dose Conversion Factors

Photon and neutron fluence-to-dose conversion factors were taken from ICRP publication 51, Table I: "Effective dose equivalent per unit fluence for photons incident in various geometry on an anthropomorphic phantom."² Since the actual irradiation geometry at the HTTR is unknown, a conservative geometry, the anteroposterior irradiation was chosen.

Table I. Fluence-to-Dose Conversion Factors						
Photons				Neutrons		
	ICRP-21	ICPR-51			ICRP-21	ICRP-51
Energy	(rem/hr)	(rem/hr)		Energy	R/h	R/h
(MeV)	(p/cm ² s)	(p/cm ² s)		(MeV)	(n/cm ² s)	(n/cm ² s)
1.00E-02	2.78E-06	2.23E-08		2.53E-08	3.67E-06	2.88E-06
1.5E-02	1.11E-06	5.65E-08		1.0E-07	3.67E-06	3.17E-06
2.0E-02	5.88E-07	8.57E-08		1.0E-06	4.46E-06	3.47E-06
3.0E-02	2.56E-07	1.18E-07		1.0E-05	4.54E-06	3.21E-06
4.0E-02	1.56E-07	1.31E-07		1.0E-04	4.18E-06	2.98E-06
5.0E-02	1.20E-07	1.38E-07		1.0E-03	6.76E-06	2.76E-06
6.0E-02	1.11E-07	1.44E-07		1.0E-02	3.56E-06	3.26E-06
8.0E-02	1.20E-07	1.62E-07		2.0E-02		4.23E-06
1.0E-01	1.47E-07	1.92E-07		5.0E-02		7.85E-06
1.5E-01	2.38E-07	2.80E-07		1.0E-01	2.17E-05	1.43E-05
2.0E-01	3.45E-07	3.71E-07		2.0E-01		2.78E-05
3.0E-01	5.56E-07	5.62E-07		5.0E-01	9.26E-05	6.26E-05
4.0E-01	7.69E-07	7.42E-07		1.0E+00	1.32E-04	1.03E-04
5.0E-01	9.09E-07	9.14E-07		1.5E+00		1.32E-04
6.0E-01	1.14E-06	1.08E-06		2.0E+00		1.54E-04
8.0E-01	1.47E-06	1.38E-06		3.0E+00		1.90E-04
1.0E+00	1.79E-06	1.66E-06		4.0E+00		2.16E-04
1.5E+00	2.44E-06	2.25E-06		5.0E+00	1.56E-04	2.35E-04
2.0E+00	3.03E-06	2.76E-06		6.0E+00		2.50E-04
3.0E+00	4.00E-06	3.67E-06		7.0E+00	1.47E-04	2.63E-04
4.0E+00	4.76E-06	4.50E-06		8.0E+00		2.74E-04
5.0E+00	5.55E-06	5.29E-06		1.0E+01	2.08E-04	2.95E-04
6.0E+00	6.25E-06	6.01E-06		1.4E+1	2.27E-04	3.46E-04
8.0E+00	7.69E-06	7.49E-06				
1.0E+01	9.09E-06	8.89E-06				
*This ICRP 51 neutron conversion factors in pico Sv/cm ² are the pre-1985 formulation. The new values are twice the 1985 values. The factors in rem/hr/(n/cm ² s) have the factor of two accounted for. ICRP 51 values are effective dose equivalents for anteroposterior (AP) radiation by beam.						

3.0 Calculational Model

Figure 1 shows the relative position of the door valve and fuel-handling machine during the fuel handling. The calculations were performed for the design basis HTTR fuel positioned in the door valve. Only one fuel position depth and one monitor of the HDVM were considered owing to computer time limitations. As only one monitor of the HDVM is modeled, the calculated dose rate at a distance of 1 m from the door valve should be multiplied by a factor of 2 to conservatively estimate the contribution of another monitor. Actually, the fuel handling machine will contain some spent-fuel blocks during fuel handling. Their contribution to the dose rate is negligible because the fuel handling machine has enough thickness to shield radiation. Also, the contribution through the gate of the door valve from the spent-fuel blocks inside the fuel handling machine is also negligible because the solid angle along the track of radiation is very small. From the above mentioned, this calculational model is adequate to evaluate the dose rate from the spent-fuel block during the fuel handling.

Fig. 1. Door valve and fuel handling machine.

3.1 Door Valve Monitor Model

The three dimensional MCNP model of the HTTR penetration and HDVM is shown in Fig. 2. Figure 2 shows the geometry of the MCNP model which includes artificial cells added for importance sampling.

Fig. 2. Door valve monitor MCNP model.

3.2 Spent Nuclear Fuel Characteristics

The fuel parameters used in this calculation are presented in Table II.

For the purpose of the calculation, the spent-fuel block was modeled as a cylindrical and homogenized mixture of graphite block, graphite sleeve, and fuel compact.

Table II. Spent Nuclear Fuel Modeled Characteristics	
Reactor type:	High-Temperature Gas Reactor
Assembly type:	Pin-in-block typed fuel (standard)
Burnup:	35,000 MWd/MTU
Age:	10 days
Fuel Compact	
Type:	Hollow cylinder
Materials:	Coated fuel particles, binder, and graphite
Packing fraction of coated fuel particle:	30%
Outer/inner diameter:	26/10 mm
Height:	39 mm
Active length of the fuel rod:	546 mm (including 14 fuel compacts)
Graphite Sleeve	
Type:	Cylinder
Material:	Graphite
Outer diameter:	34 mm
Thickness:	3.75 mm
Length:	580 mm
Gap width between compact and sleeve:	0.25 mm
Graphite Block	
Type:	Hexagonal and pin-in-block
Material:	Graphite
Number of fuel rods:	33
Width of flat across:	360 mm
Height:	580 mm
Fuel hole diameter:	41 mm
Uranium weight per block:	6.2 kg
Graphite weight per block:	93.9 kg
Homogenized Model	
Assembly weight:	100.4 kg
Active volume:	$6.169 \times 10^4 \text{ cm}^3$
Density:	1.627 g/cm^3
Mass Fractions	
Graphite:	0.941
^{235}U :	0.003
^{238}U :	0.056

3.3 Photon and Neutron Source Strength and Energy Spectrum

The energy spectrum and source strength for the primary photon and neutron were taken from the HTTR design basis and are shown in Tables III and IV.

Table III. Gamma spectrum of Spent-Fuel Block	
Energy (MeV)	Intensity of gamma ray (photon/s)
0.00 ~ 0.15	6.5×10^{15}
0.15 ~ 0.30	6.5×10^{14}
0.30 ~ 0.45	5.3×10^{14}
0.45 ~ 0.70	1.6×10^{15}
0.70 ~ 1.00	2.2×10^{15}
1.00 ~ 1.50	1.5×10^{14}
1.50 ~ 2.00	6.2×10^{14}
2.00 ~ 2.50	3.5×10^{13}
2.50 ~ 3.00	2.3×10^{13}
3.00 ~ 4.00	2.0×10^{11}
4.000 ~ 6.00	2.0×10^5
6.00 ~ 8.00	2.3×10^4
8.00 ~ 14.0	2.6×10^3
Burnup: 35 GWD/tU Power density: 6.0 W/cc Cooling time: 10 days	

Table IV. Neutron Spectrum of Spent-Fuel Block	
Energy (MeV)	Intensity of Neutron (n/s)
$5.8 \times 10^{-4} \sim 3.4 \times 10^{-3}$	3.7×10^2
$3.4 \times 10^{-3} \sim 1.1 \times 10^{-1}$	7.3×10^4
$1.1 \times 10^{-1} \sim 5.5 \times 10^{-1}$	6.0×10^5
$5.5 \times 10^{-1} \sim 1.1$	8.9×10^5
1.1 ~ 1.8	9.9×10^5
1.8 ~ 2.4	5.6×10^5
2.4 ~ 2.5	1.0×10^5
2.5 ~ 3.0	4.4×10^5
3.0 ~ 4.1	5.6×10^5
4.1 ~ 5.0	2.8×10^5
5.0 ~ 6.4	2.2×10^5
6.4 ~ 8.2	1.1×10^5
8.2 ~ 10	3.6×10^4
10 ~ 12.2	1.3×10^4
12.2 ~ 14.9	3.4×10^3

4.0 Results

The dose estimates are shown in Table V. The doses were calculated using a track-length estimator in the cell and thus represents the average dose in a region, not the peak dose. However, the regions were sufficiently thin so that the calculated doses are accurate. Also included for comparison are calculations for a 55-cm-thick iron shield with no penetrations, the approximate thickness of the door valve (case 2 and 3), the temporary plug (case 3), and the case to estimate the contribution of the streaming path to the reference monitor design (from case 5 to 8). The temporary plug, which is being installed at the door valve, fills the penetration for the HDVM.

The doses are statistical estimates and as such have an associated statistical error. An estimate of the relative percent error is included in parentheses along with the dose estimate. The error listed is the precision not the accuracy.

The absolute dose-rate level is a strong function of the flux-to-dose conversion formulation and the radiation geometry, which in combination can change the absolute dose rate level by a factor of 2 or more. The ratio of dose for no penetration vs with penetration is expected to be much less sensitive to the conversion factors used.

An estimate of the count rate and an evaluation of the integrity of the ^3He tube inside the stainless-steel package were performed. The count rate and gamma dose are 3.26×10^2 counts/s (in case 7) and 4.31 R/h (in case 1).

In conclusion, the tungsten shielding included in the detector package is sufficient to reduce the gamma dose during reactor unloading operations to an acceptable value.

Table V. Calculated Dose Rates			
Case	Description	Surface Dose mR/h	1 meter Dose ^{*1} mR/h
1	Reference Monitor Design (gamma) ^{*2}	11.8 (13)	4.18 (29)
2	55-cm Iron Shield (gamma)	1.80 (2)	0.82 (22)
3	55-cm Iron Shield (neutron)	0.47 (0.4)	0.08 (1.3)
4	Temporary Plug (gamma) ^{*2}	2.83 (12)	1.14 (31)
5	Monitor Design 1 (gamma) ^{*2}	27.3 (12)	9.56 (24)
6	Monitor Design 2 (gamma) ^{*2}	22.5 (15)	10.68 (23)
7	Monitor Design 2 (neutron) ^{*2}	0.27 (1)	0.08 (3)
8	Monitor Design Without Streaming Gap (gamma)	8.17 (12)	2.76 (36)
	Criteria	200	10
*1 These results are obtained by multiplying the calculation result by a factor of 2.			
*2 The streaming path to be considered is as follows:			
	Gap 1	Gap 2	Gap 3
case 1	0.3	0.3	1.0
case 4	---	---	1.0
case 5	0.3	0.3	2.0
case 6	2.0	0.0	0.0
case 7	2.0	0.0	0.0
			Unit: mm
Gap 1 is the streaming path between the nose of the main body and the ring shield made of tungsten or lead.			
Gap 2 is the streaming path between the nose of the main body and the tungsten shield inside the nose.			
Gap 3 is the streaming path between the casing of the door valve and the HDVM.			
The position of the streaming path is shown in Fig. 2.			

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