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Use of Radiation Detectors in Remote Monitoring for Containment and Surveillance

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Abstract

Radiation detectors have been included in several remote monitoring field trial systems to date. The present study considers detectors at Embalse, Argentina, and Oarai, Japan. At Embalse four gamma detectors have been operating in the instrumentation tubes of spent fuel storage silos for up to three years. Except for minor fluctuations, three of the detectors have operated normally. One of the detectors appears never to have operated correctly. At Oarai two gamma detectors have been monitoring a spent-fuel transfer hatch for over 18 months. These detectors have operated normally throughout the period, although one shows occasional noise spikes.

Introduction

Radiation detectors offer opportunities for practical containment and surveillance applications, with or without the use of remote monitoring, and have been included in several remote monitoring field trial systems to date. The present study considers detectors at two of these sites: the CANDU reactor spent fuel storage silos of Central Nuclear Embalse in Cordoba Province, Argentina, and the Joyo reactor spent fuel storage pond number 3 at Oarai, Japan. The remote monitoring field trial systems installed at these sites have been described elsewhere.[1]

Embalse. The remote monitoring system at the Embalse site was installed in March 1995. It includes four battery-powered gamma ray detectors located in the instrumentation tubes of four spent fuel storage silos. Each detector measures the gamma ray dose rate at one location in the instrumentation tube. The readings are reported to the remote monitoring system computer via RF transmission every 74 minutes. In safeguards use, an inspector would be looking for a change in the measured dose rate that might indicate a discrepancy in the continuity of knowledge about the spent fuel.

During the original installation, Geiger-Muller detectors were installed in instrumentation tubes on silos 31 and 36, and solid-state silicon detectors were installed in the tubes of silos 21 and 26. The silicon detectors degraded over time and were replaced in May 1996 with ion chambers.[2] Only data from the G-M tubes and ion chambers will be considered here.

Joyo. Installation of the remote monitoring system at the Joyo site was completed in October 1996. This system includes two gamma detectors and one neutron detector. All of the detectors use site power and are hard-wired to the remote monitoring system computer via an Echelon Lonworks® network. Only data from the gamma detectors will be discussed here.

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[1] S. A. Dupree, C. S. Sonnier, and C. S. Johnson, "Remote Monitoring in International Safeguards," *JNMM XXIV*, January 1996. pp. 19-30. M. Ross, et al., "PNC/DOE Remote Monitoring Project at Japan's Joyo Facility," *Proc INMM 37*, 1996. pp. 1003-1008.

[2] The solid state detectors and ion chambers were supplied by Oak Ridge National Laboratory.

DISCLAIMER

Gamma-ray readings are taken every five seconds. Whenever a preset threshold level of 20 counts in 5 seconds is reached or exceeded the result is recorded. Even if the threshold level is not exceeded, one reading is recorded every 20 minutes. Thus a series of background measurements is accumulated along with any significant excursions above background.

The Joyo gamma detectors are mounted on the sides of a hatch through which flasks containing spent fuel and other items to be stored in pond 3 must pass. The purpose of the gamma detectors is to determine whether flasks entering or leaving the storage area contain radioactive material. In safeguards use an inspector would examine the data to evaluate the movement of radioactive materials, and confirm that all flasks exiting the area are empty, and thus that all materials brought into the storage area remain in the area.

Results

Silo 31. At Embalse it was found that the amplifier gains vary with temperature.[3] Temperature sensors located in the RF transmitter units must be used to correct for this effect. The temperature-corrected dose rate for silo 31 for the period 29 March-18 May 1995 is shown in Figure 1.[4] There are a number of readings shown in Figure 1 that lie well outside the expected statistical range of the data. The value of 63.7 (reading number 713), for example, is more than 5 standard deviations above the mean. The probability of obtaining a single such reading for a normally distributed variable is less than 10^{-6}, yet there are six other data points in the set shown that are even further from the mean. Since there are only 993 data points in the set, these outlying points are clearly not statistical in origin.

The high-side outliers in Figure 1 appear in about 1% of the readings. Although annoying, they are not of major concern for possible safeguards evaluation because they occur in isolation; i.e., there is no sequence of several anomalous readings over an extended period of time. These outliers are consistent with readings occurring at the boundary between two levels in an analog-to-digital converter (ADC). Thus it might be speculated that they are related to the low-resolution, 8-bit ADC used in the Embalse system hardware.[5]

The radiation dose rates in Figure 1 show a clear decline with time. Over the 51-day period covered by the data shown, there is a drop in the average dose rate from about 0.595 Gy/hr to near 0.589 Gy/hr, or about 1%. This agrees favorably with the expected decline in the gamma activity of spent fuel that has been cooled for 10 years or so. It seems clear that the effect of fission product decay is being observed.

Another block of data from silo 31, this time for the period May 16-October 3, 1996, is shown in Figure 2. Here the data have again been temperature corrected, but the correction is less effective in smoothing these data than it was for the data in Figure 1.[6] The decline in the dose rate from decay of the spent fuel continues to be a prominent feature of the data.

The safeguards application being examined in the remote monitoring field trial in Embalse is that of monitoring spent fuel in long-term storage using radiation detectors. The alarm condition sought, therefore, would be an extended period in which readings significantly below the norm were recorded. That is, the alarm condition would be approximately that shown in Figure 2 in the vicinity of reading 2471. Over a period of 24 hours, on September 23-24, 1996, the radiation readings of the gamma sensor in silo 31 were consistently low, though only by about 15%. If this system had been in use for safeguards purposes this result would surely have caused consternation. One possible explanation for the low readings on September 23-24 is that the temperature over the period was quite low, and the diurnal change was unusually small. This

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[3] A. Bonino, et al., "The International Remote-Monitoring Project: Results of the First Year of Operation at Embalse Nuclear Power Station in Argentina," *JNMM XXV*, June, 1997. pp. 81-84.

[4] A linear temperature correction has been used. For several reasons, this will not completely eliminate the impact of temperature changes on the dose-rate reading. The dose rate decreases as the fuel decays, there is no *a priori* reason to expect the temperature effect on the electronics to be linear, and the location of the temperature measurement is not inside the detector electronics. Nevertheless, much of the effect can be removed by using a linear relationship.

[5] The linearity of the ADC is unknown. The analog output from the detector was set near the center of the ADC operating range. Random errors in the setting of high-order bits might account for the observed results.

[6] The cause of this change might be radiation exposure on the signal cable or changes in the high voltage caused by repetitively switching the circuit on and off. In the three-year operating period of the system, through May of this year, the circuits have been switched on and off more than 20000 times.

indicates that it was probably cloudy, and the possibility of a storm seems significant. A combination of moisture and cold could have affected the electronics in a way not otherwise observed during the field trial, and could explain the low readings.

Silo 36. The second G-M tube installed as part of the remote monitoring field trial was placed in silo 36. The data from this sensor was found to be more sensitive to temperature than that from silo 31, and the linear temperature correction left a significant residual effect. The readings for the period 29 March-25 June 1995 are shown in Figure 3. Again some outlying points are observed, but the frequency of such outliers is less than for the detector in silo 31. There is again a clear indication of the decay of the spent fuel.

Figure 4 shows the temperature-corrected silo 36 data for the period 16 May – 3 October 1996. Again the correlation between dose rate and temperature has changed and there are strong residual temperature effects visible in the data. Furthermore, the statistical fluctuations indicated by the spread in the readings are not symmetric. That is, there is much more spread in the results above the mean than in those below the mean. This could be caused by non-linearities in the ADC and the fact that the analog signal may be near the boundary of one of the high-order bits in the ADC. The data continue to show a declining dose rate caused by the decay of the spent fuel.

Silo 21. The temperature-corrected dose rates from silo 21 for 16 May – 3 October 1996 are shown in Figure 5. The correlation between dose rate and temperature is again poor and some residual temperature effects are visible. Furthermore, the dose rate for silo 21 does not show an obvious decline over the 140-day period covered by the data. Figure 6 shows the silo 21 temperature-corrected dose rates for the period 30 Jan – 21 March 1998. These data are similar in quality to those of Figure 5 except for two periods of fluctuation around readings 250 and 360, corresponding to the dates of February 12 and 17. The maximum decrease in the dose rate during these fluctuations is again about 15%. The source of these fluctuations is unknown.

Silo 26. The detector emplaced in silo 26 has exhibited a number of anomalies. There are apparent problems with the ADC and there is a general downward trend in the data that is more rapid than would be credible for spent fuel decay. This probably indicates a change in the sensor, the cable, or the electronics with time. In 1998 the detector showed a rapid change in output resulting in repeated saturation of the ADC, alternating with periods of zero output. The data show every indication of a short having developed in the system, possibly caused by moisture in the cable. The detector in silo 26 appears never to have worked correctly.

Joyo Gamma sensor 1. There is a significant variation in the background readings from the Joyo sensors. The background generally peaks twice daily – once in the morning and once in the afternoon. The cause of these peaks may be radon buildup inside the facility. Data from Joyo gamma sensor number 1 for the months of December 1997 and January 1998 are shown in Figure 7. Here a moving 6-hour average background is subtracted from the instantaneous readings. This removes the major swings in the background and reveals the random variation around these swings. There were two, isolated threshold events during this period, both of which recorded exactly 20 counts. This is statistically reasonable for the approximately 4500 data points collected in this period.[7]

Joyo Gamma sensor 2. Data from Joyo gamma sensor number 2 for the months of December 1997 and January 1998, differenced from a moving, 6-hour average background, are shown in Figure 8. There were numerous threshold events for gamma detector 2 during December, including several sequential sets of events well above the trigger level. However, the data are inconsistent with the presence of a radiation source, which should have shown numerous sequential rising and falling readings as it passed the detector. In addition, a source would have been seen by both Joyo detectors.

The origin of these anomalous readings in sensor 2 is unknown. Figure 8 shows that the largest excursions occurred in early December, and that large excursions apparently stopped

[7] For this radiation measurement, with a mean of 5.4 counts, the statistical probability of obtaining 20 counts in any one 5-second interval is 8.5×10^{-7}. There were 1.07×10^{6} 5-second measurements taken during this 62-day period; therefore, we would expect an average of about one triggered event over this period. However, the daily fluctuations in the background are sufficiently large that the actual probability of obtaining 20 counts may be different from this average estimate. In any case, the two events recorded by gamma sensor 1 in December and January are not inconsistent with the data and are probably statistical in origin.

near the end of the month. This is confirmed in data from February and March. There was no activity in the facility at the time of the December events, and in no case are the excursions confirmed by the known presence of a radiation source[8] or by the response of gamma sensor 1. It is clear that these are spurious events that are not statistical in origin. It is possible that the excursions are microphonic in origin, caused by vibration of the sensor from industrial activities near the facility, or by other industrial noise. If so, this industrial noise apparently deceased near the end of December.

Gamma sensor 2 continues to be subject to infrequent excursions above the detector threshold. None of these excursions has been correlated with activity in the facility, and none have been confirmed by the data from sensor 1. Though these excursions are annoying, they are not necessarily unacceptable, particularly in a redundant system such as that at Joyo. Sensor 2 is more sensitive than sensor 1, and this sensitivity would appear to justify increasing the threshold of this detector to 21 or 22 counts, which would eliminate many of the threshold events and bring its performance into better agreement with sensor 1.

Conclusions

The gamma detectors considered here have functioned continuously in field trials for several years. Much has been learned from their operation, and the relatively few problems encountered have helped provide a basis for future improvement. Important areas to consider in future applications include minimizing temperature effects in outdoor applications and use of redundant sensors to minimize false alarms. Reliability will be an important issue in the practical application of radiation sensors to continuous monitoring.

Acknowledgment

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[8] Routine movement of materials into the pond 3 facility occurred in 1996. Events recorded at that time showed the gradual rise and fall expected from such sources, and were confirmed by both detectors.

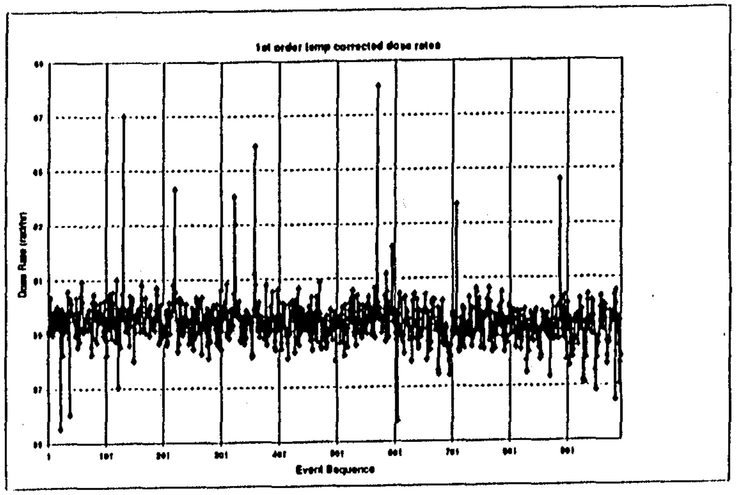

Figure 1. Silo 31 Data, 29 March – 18 May 1995

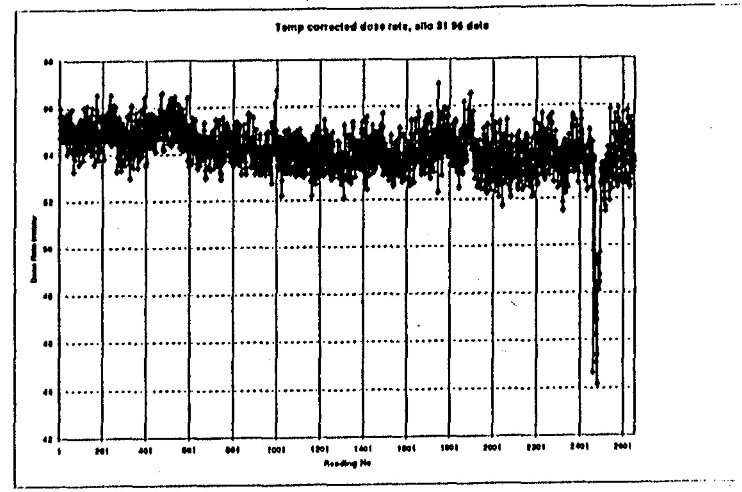

Figure 2. Silo 31 Data, 16 May – 3 October 1996

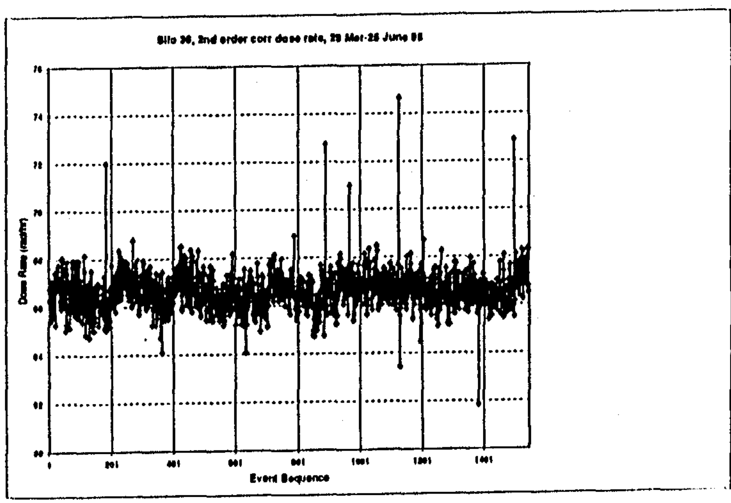

Figure 3. Silo 36 Data 29 March – 25 June 1995

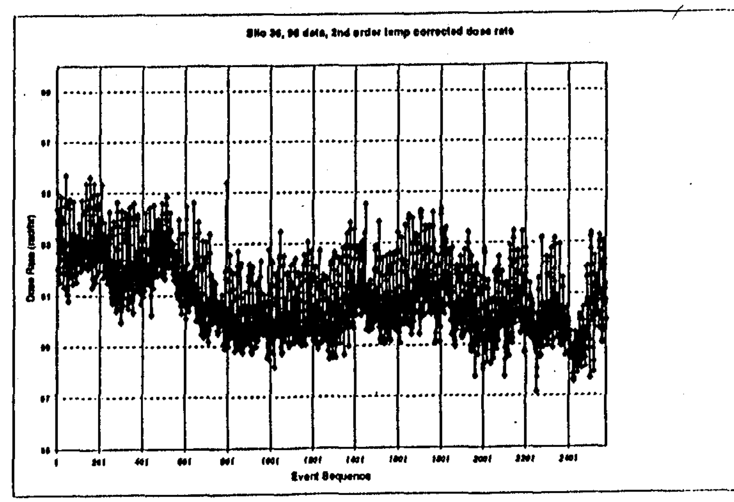

Figure 4. Silo 36 Data 16 May – 3 October 1996

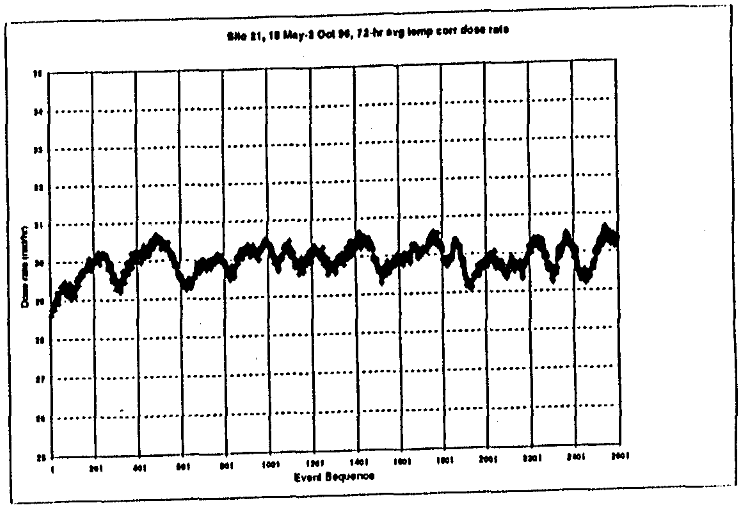

Figure 5. Silo 21 Data 16 may – 3 October 1996

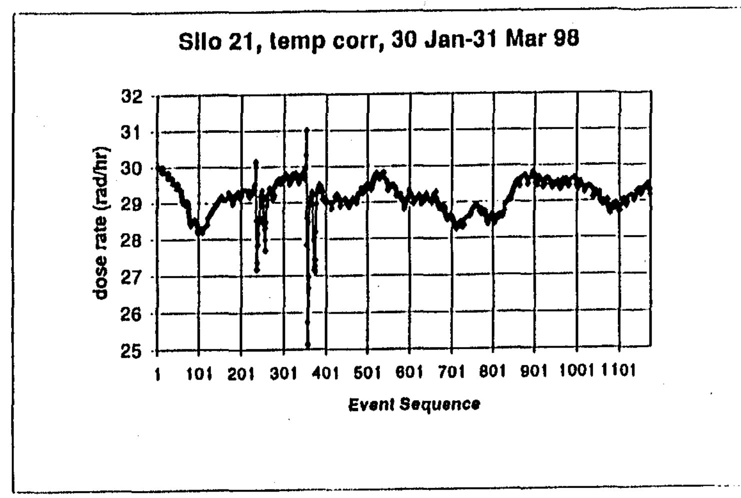

Figure 6. Silo 21 Data 30 January – 31 March 1998

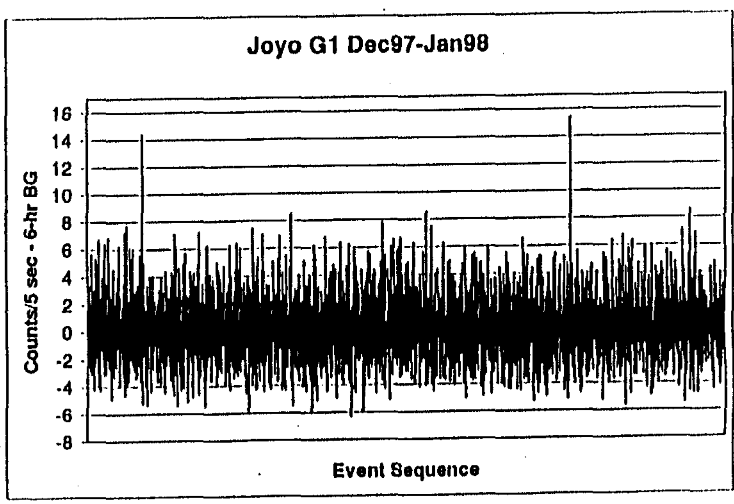

Figure 7. Joyo Gamma Sensor 1 Data 1 December 97 – 31 January 98

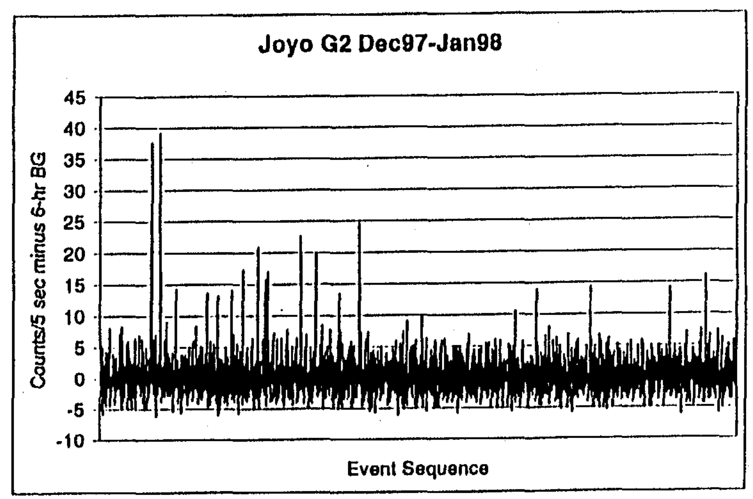

Figure 8. Joyo Gamma Sensor 2 Data 1 December 97 – 31 January 98