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INFORMAL REPORT

TMI-2 SOURCE AND INTERMEDIATE RANGE NEUTRON FLUX MONITORS DATA REPORT

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EG&G Idaho

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ABSTRACT

This is a report on the preparation of data from the TMI-2 excore source and intermediate range neutron flux monitors for inclusion into the TMI Data Base. The sources of the as-recorded data are discussed as well as the process of transforming these data into digital form. The corrections to the as-recorded data are given and the data quality classification and uncertainty are established. The identifiers attached to each data set in the TMI Data Base are given.

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DATA REPORT

INTRODUCTION

This report is concerned with data from the two source range (SR) and two intermediate range (IR) neutron flux monitors whose detectors are mounted just outside of the reactor vessel. These two systems cover the lowest two ranges of the three overlapping neutron flux monitoring systems used at TMI-2 (the third is the power range monitor system). The SR system is used to monitor reactor neutron flux from startup to a very low value of reactor power, while the IR monitor overlaps with the SR and continues to about 100% reactor power.

The purpose of this report is to provide background information on the SR and IR neutron monitor data which are being put into the TMI-2 DATA BASE. The information given here indicates where the data originated and how it was corrected to its final state. It specifies the data identifiers, qualification category and the associated uncertainty. In addition, descriptions are given of the instruments, location and relationship between reactor and detectors, and details of how the data were digitized and corrected. Zero time for all data was set at the turbine trip time of 04:00:37.

The data reported here are from the same data sources as that analyzed in NSAC-80-1 and NSAC-28 (the stripcharts from recorders 66 and 128) and also from the plant computer periodic log. The SR monitor data from the periodic log is unique in that it has not been previously published.

MEASUREMENT CHANNELS

Each of the SR and IR neutron monitors consisted of a number of instrument components connected together to form a measurement channel. These channels contained a detector sensitive to the neutron flux, a signal conditioning and amplifying section, and a strip chart recorder and computer printout. Figures 1 and 2 are block diagrams of each of the two types of channels showing the major components of interest in this report.

In the SR measurement channels the neutron detectors were BF_3 filled proportional counters about 75 cm long and mounted at the reactor midplane between the vessel and the biological shield. The detectors were mounted azimuthally 180 degrees apart as shown in Figure 3. A preamplifier was mounted in the reactor building to convert electrical charge to voltage. The voltage amplifiers, discriminators, and power supplies were located in the control building. The output of the count rate amplifier was a voltage proportional to the logarithm of the incoming count rate and was sent to both a stripchart recorder and to the plant computer. The measurement from SR detector NI-1 was recorded on recorder No. 128, but SR detector NI-2 was not connected to a stripchart recorder. Both channels were connected to the plant computer, however.

The SR monitor detector high voltage was interlocked with the reactor control rod system so that the high voltage was disconnected before the neutron flux exceeded the operating specifications for the detector (10^6 neutrons per cm^2 per second). This resulted in a greatly increased lifetime for the BF_3 detectors, but meant that the SR detectors were not active at the time of the reactor scram. The SR monitors did not begin to operate until some minutes

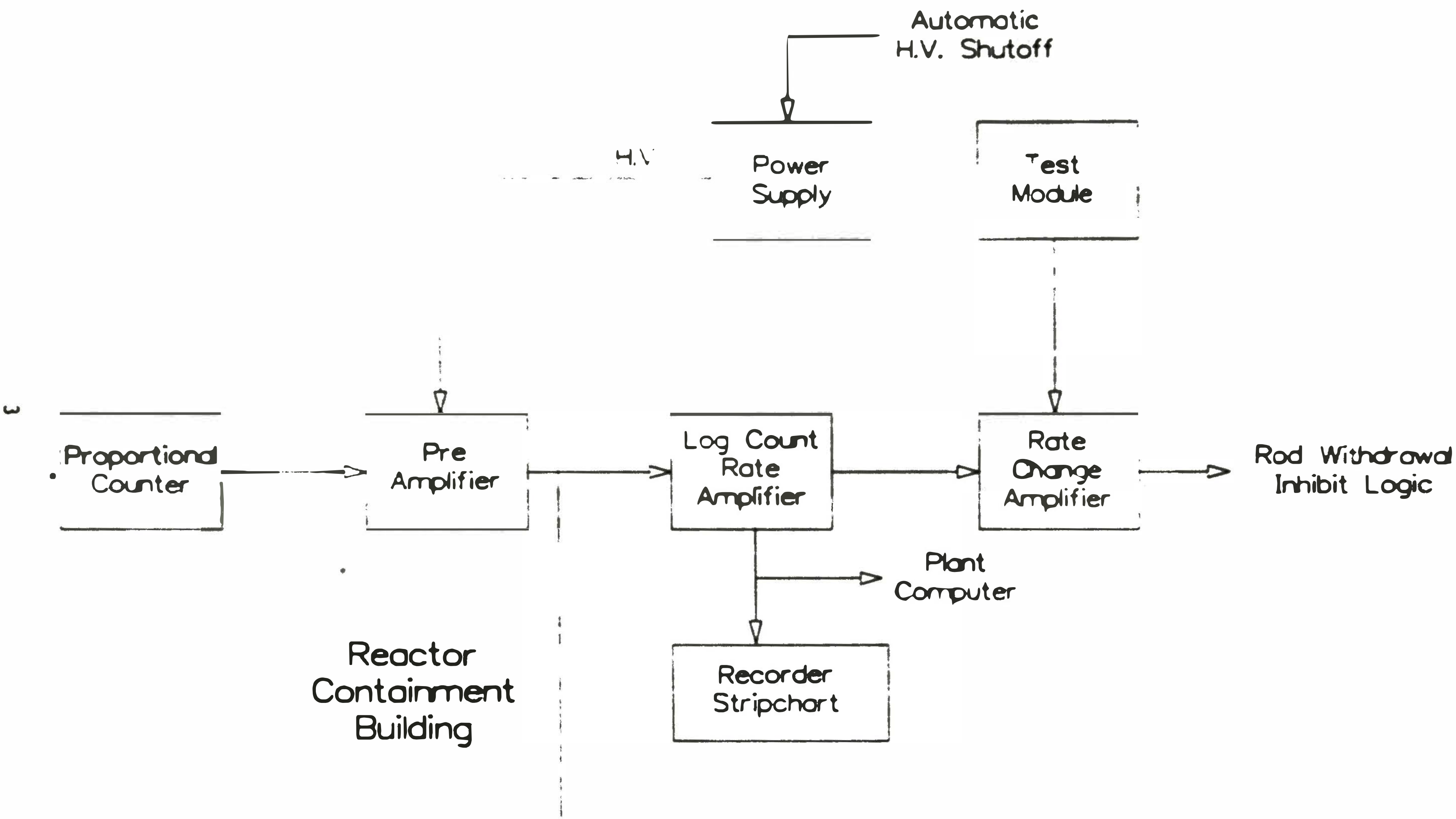

Figure 1. Block Diagram of Source Range Monitor Channels

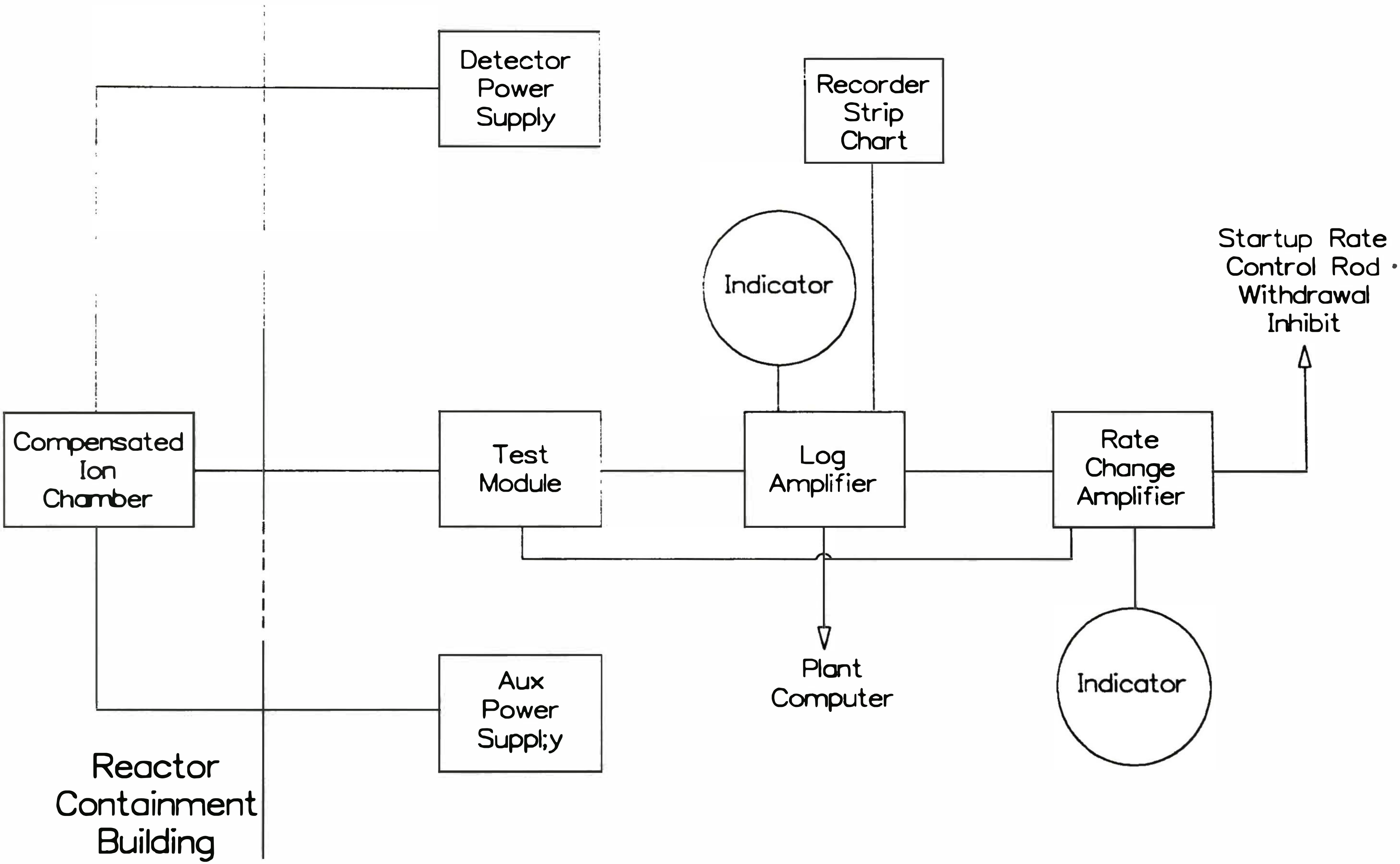

Figure 2. Block Diagram of Intermediate Range Monitor Channels

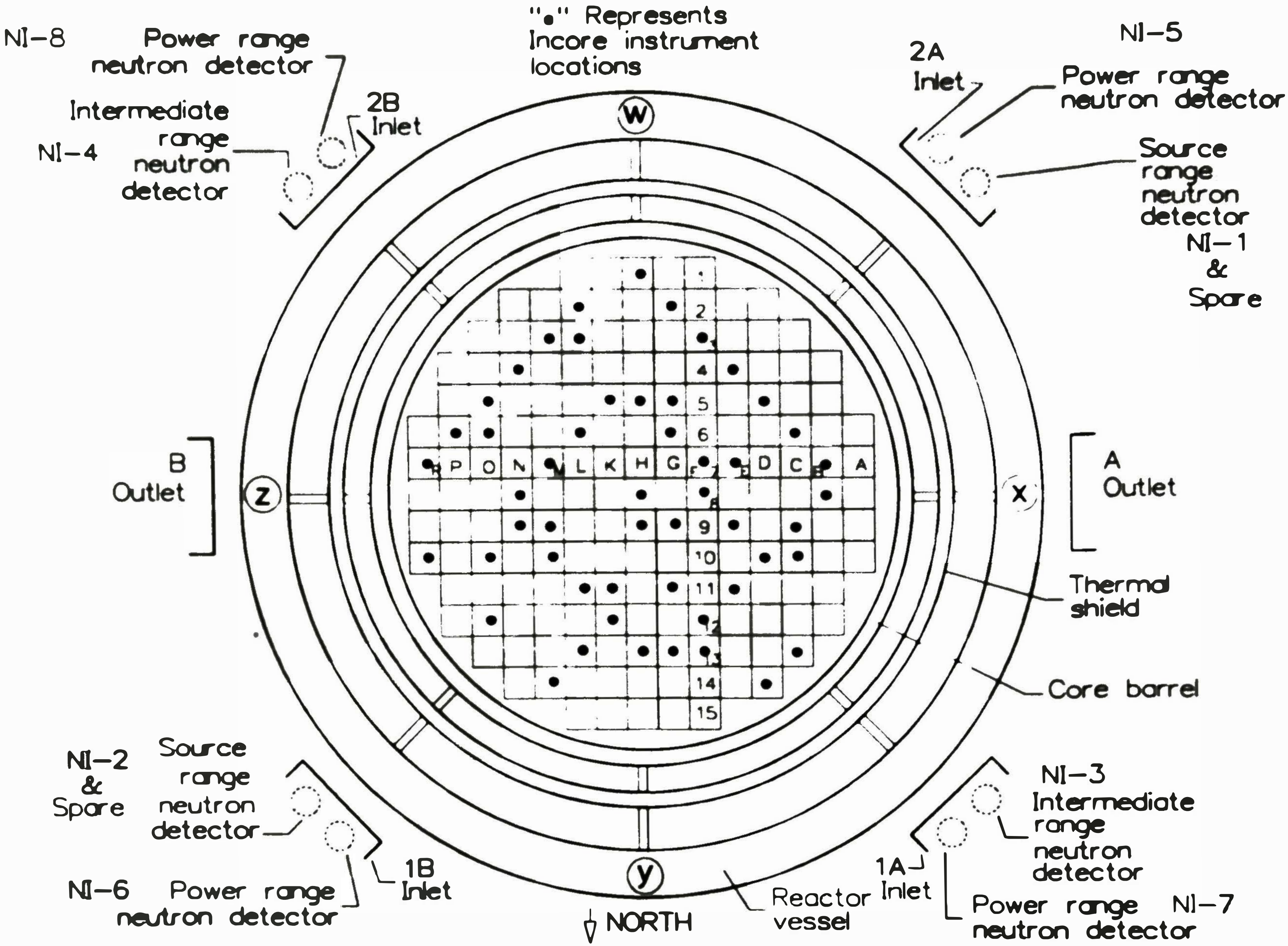

Figure 3. Top View of Reactor Core

after scram at the beginning of the TMI accident. The SR stripchart response was at a low value at the beginning of the accident (with no high voltage on the detector), it raised quickly at about nine minutes into the accident (when high voltage was restored) and then began to fall off at a normal reactor decay rate.

In the IR monitor measurement channel, detectors NI-3 and NI-4 were electronically compensated ion chambers about 75 cm long and mounted at the midplane of the reactor similarly to the SR detectors. Figure 3 shows the location of the IR detectors. The amplifiers and power supplies for these monitors were located in the control building. A voltage representative of the logarithmic output of the amplifiers was sent to recorders (NI-3 to No. 66 and NI-4 to No. 128) and also to the plant computer.

DATA MANIPULATION

All time series data put into the TMI Data Base must be in digital form, therefore, all the SR and IR analog stripcharts had to be digitized. A special digitizing apparatus was used where the stripchart was mounted on an accurate x-y axis board. The x and y coordinate values were then fed directly into the computer by following the curve with a stylus which was periodically triggered. Both SR monitor NI-1 and IR monitor NI-4 data were on pen stripchart recorder No. 128. These data were digitized from microfiche film of the original strip charts for a total of 25 hours after the turbine trip.

In order to reduce errors due to optical distortion in the microfiche of the SR curve, the stripchart was digitized in 10 segments and then reassembled. The time-base was adjusted to zero by aligning corresponding perturbations on the SR curve to those on the IR curve. The timing of significant plant events were then checked against the digitized curve's time-base and found to be in reasonable agreement. The amplitude of the microfiche SR curve was reduced by a factor of ten because a multiplier had apparently been used to ease reading of the stripchart. Also the stripchart legend read "counts per minute" when in fact the time units were seconds. The existence of this multiplier and the error in the legend were confirmed by printouts on the plant computer and also by published TMI-2 documents[1-3]. After the factor of ten was removed there was excellent agreement between the computer printout values and the stripchart curve (both microfiche and digitized). Appendix A contains an uncertainty analysis which gives the uncertainty in the magnitude and time base of the data as put in the TMI Data Base.

Basically the same digitizing procedure was used for the IR (NI-4) curve on pen recorder No. 128. This curve was digitized in seven segments and then reassembled. The time-base was adjusted to zero eight second prior to the time of curve drop from steady state reactor operation, i.e., to eight seconds prior to reactor scram. Again the times of the significant plant events on the reconstituted curve were in reasonable agreement with the published times. The amplitude of this curve was adjusted, using a multiplier, so that the steady state value just prior to the reactor trip agreed with the value on the computer printout.

Data from the plant computer were found only on the periodic log which printed once every hour. The only source of the monitor NI-2 data was on the periodic log since there was no stripchart recording made of this measurement. The NI-1 and NI-2 data were taken from the periodic log for some 13 hours after the accident. No corrections were made to the magnitude of these data but the real-time base was converted to zero time at turbine trip (04:00:37).

The IR monitor (NI-3) on pen stripchart recorder No. 66 was digitized and then adjusted exactly as the IR monitor NI-4 had been. Figures 4, 5, 6 and 7 are computer plots of the digitzed data for SR and IR monitors which have been included in the TMI Data Base.

Figure 4 shows the SR monitor NI-1 data for 25 hours after turbine trip along with a normal decay curve for this type of reactor. The two curves nearly coincide at the time when the last reactor coolant pump was shut off ~ 05:41. The ordinate is the log of the counts per second.

Figure 5 is a semilog plot of data from the two SR monitors taken from the plant computer periodic log. These data were taken only at hourly intervals but are considered useful because it is the only NI-2 data which have been recorded. The ordinate is the log of the measured counts per second.

Figures 6 and 7 are plots of the IR monitor data from NI-4 and NI-3, respectively. The ordinate is the log of the detector current in amperes. Each record of measurement data has a unique identification which is used to specify the data in the TMI DATA BASE. Table 1 summarizes these identifiers.

TABLE 1

Neutron Flux Monitor Data Base Identifiers

Neutron Measurements	Recording Location	Data Identifiers
Source Range NI-1	Plant Computer	NI-ND-1P
Source Range NI-1	Recorder No. 128	NI-ND-1S
Source Range NI-2	Plant Computer	NI-ND-2P
Intermediate Range NI-3	Plant Computer	NI-ND-3P
Intermediate Range NI-3	Recorder No. 66	NI-ND-3S
Intermediate Range NI-4	Plant Computer	NI-ND-4P
Intermediate Range NI-4	Recorder No. 128	NI-ND-4S

DATA UNCERTAINTY AND QUALIFICATION

The quality of the SR/IR monitor data recorded during the TMI-2 accident and subsequently put on the Data Base was established. This was necessary so that users of these data would know the inherent errors in the data and, therefore, be able to calculate the total error band in any analyses performed with these data.

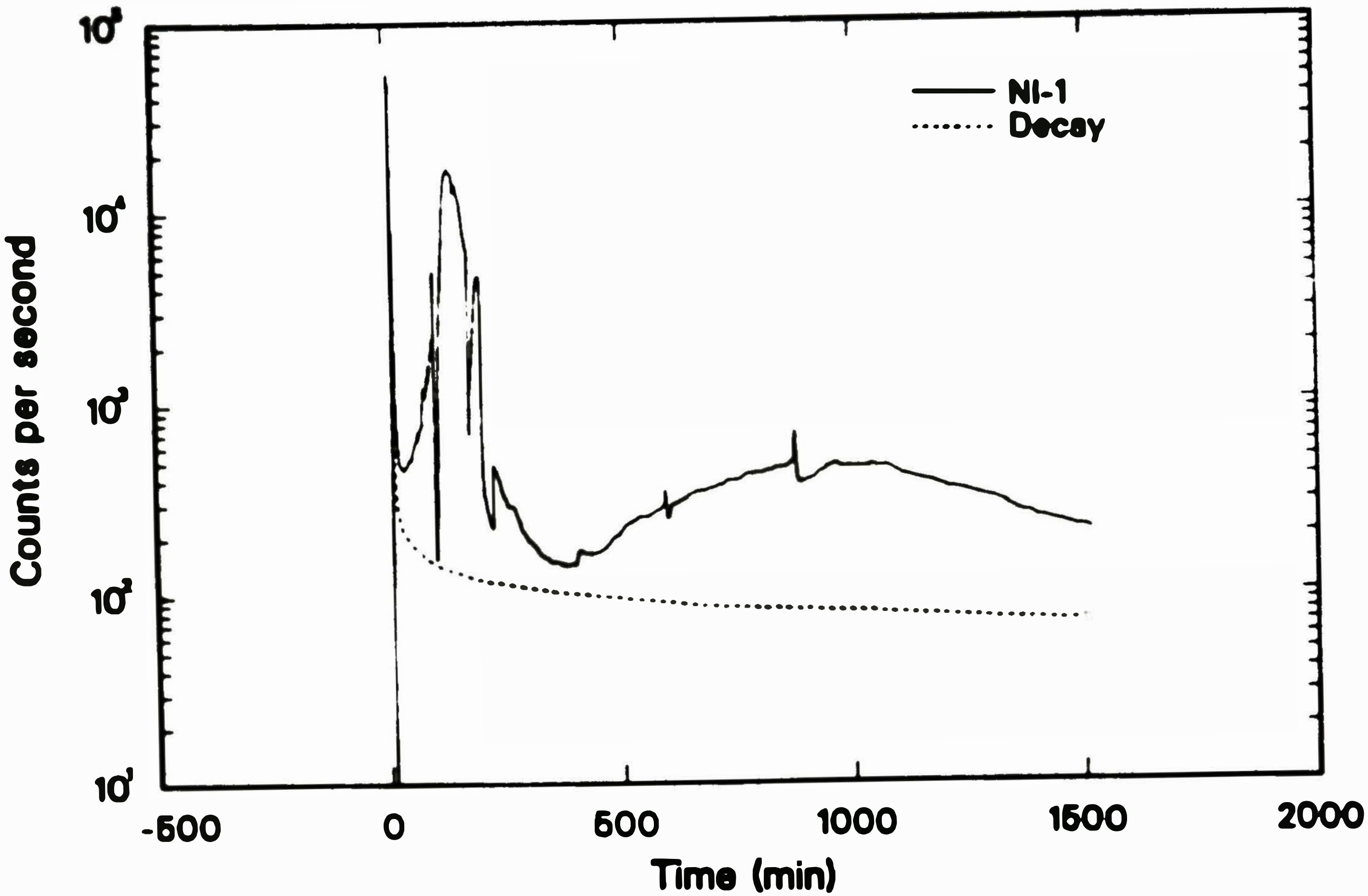

Figure 4. Source range neutron flux monitor NI-1 during TMI-2 accident with a normal decay curve

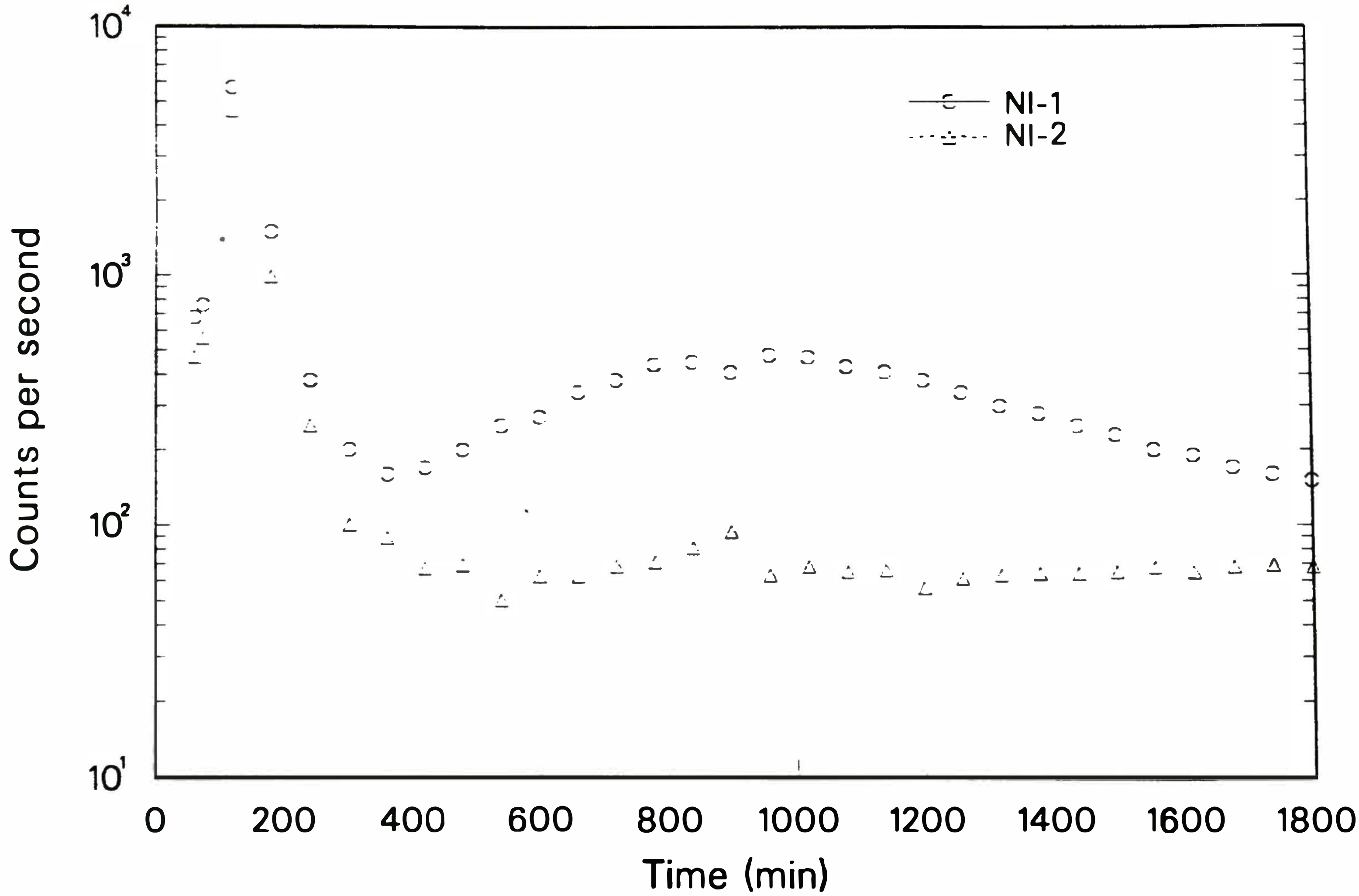

Figure 5. Source range monitors NI-1 and NI-2 from periodic log

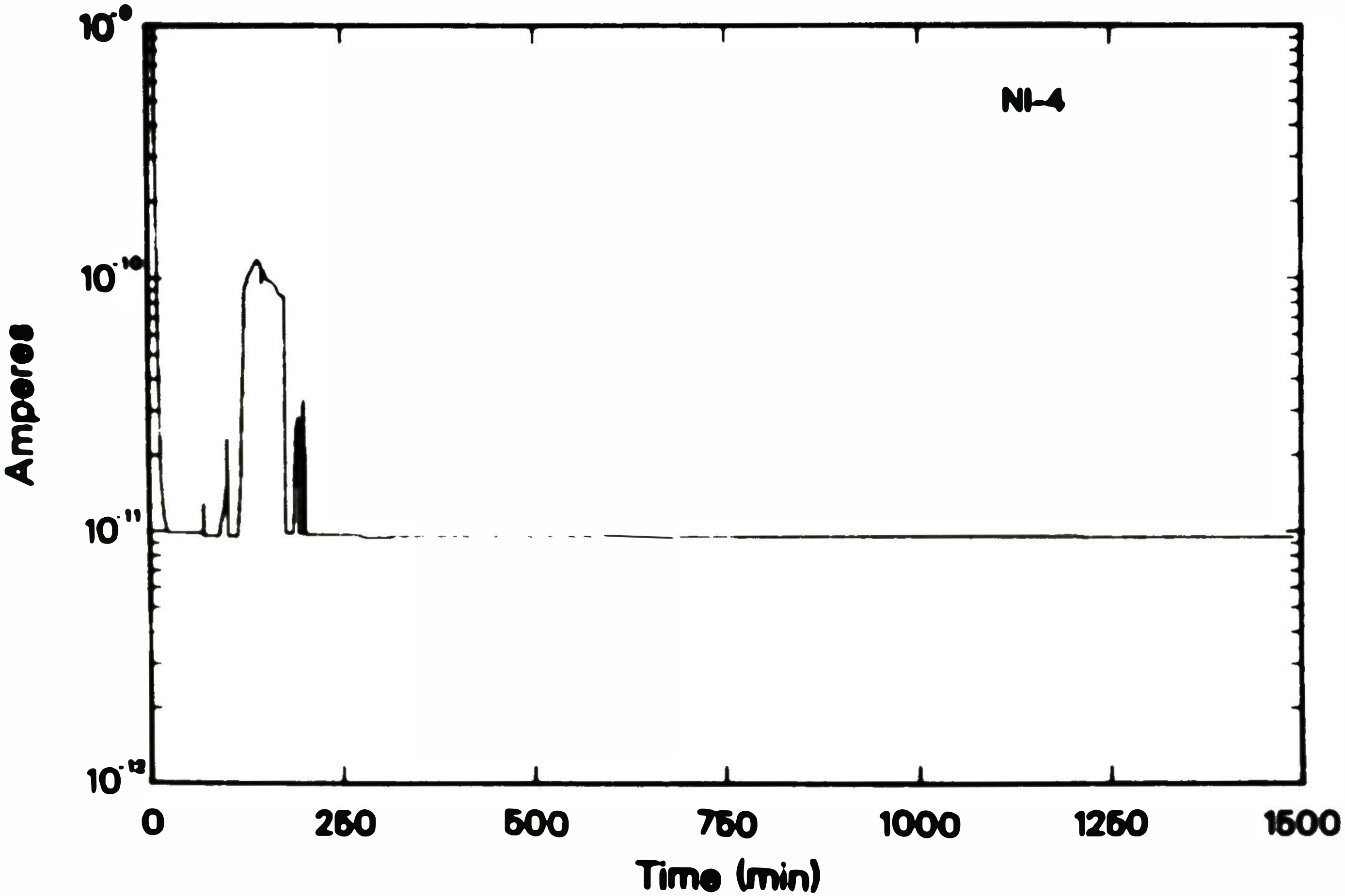

Figure 6. Intermediate range neutron flux monitor NI-4 data during TMI-2 accident.

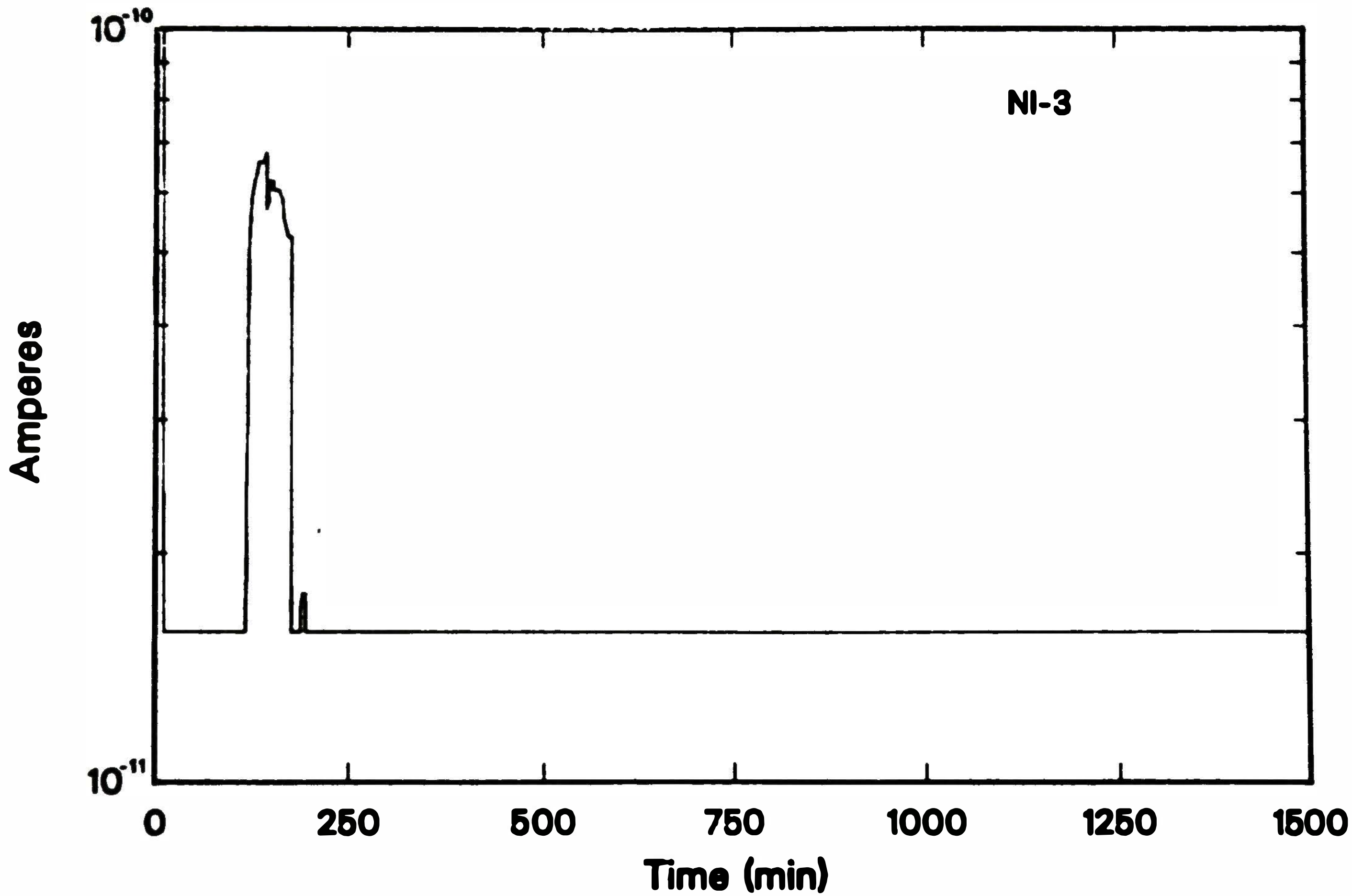

Figure 7. Intermediate range neutron flux monitor NI-3 data during TMI-2 accident.

A formal system exists for determining the uncertainty in the measurement data[4-6]. Basically, this system consists of: 1) compiling the useful data in a useable form, 2) gathering all available technical information on transducers, signal conditioning, and recording instruments, 3) gathering all available calibration data, 4) performing an uncertainty analysis on each measurement channel.

Table 2 lists the measurement identifiers, the quality classification, and the uncertainty of the SR and IR data. The "Qualified Data" is data which have established uncertainties, have been corrected for all known errors, and are considered a reasonably repeatable representation of the physical phenomenon being measured, i.e., the neutron flux at the detector location. The "Trend Data" are considered to be only a approximation of the phenomenon being measured, may not be repeatable, and have unacceptably large uncertainties.

The uncertainties shown in Table 2 are representative of the measurement channel as it was used under operating conditions. For example the SR monitor gives relative readings in counts per second and was not meant to make accurate absolute neutron flux measurements. As a measure of the absolute neutron flux value the SR monitors were inaccurate because of the count rate amplifier electronics. This circuit had poor overall accuracy but good repeatability. The IR monitors had electronics similar to those of the SR and with similar error percentages.

The difference between the SR and IR monitor uncertainties in Table 2 was due to the region of the instrument range in which each monitor was operating during the accident. At the peak accident neutron flux the SR monitor at $\sim 1.6 \times 10^4$ cps was operating four decades above its lower limit while the IR monitor at $\sim 1.1 \times 10^{-10}$ amperes was only one decade above its lower limit. In other words the SR monitor was operating well into the upper half of its range while the IR unit was near the bottom of its range. This resulted in the fixed error (based on percent of range) becoming dominant in the IR monitor. Because of this the IR monitor was classified as "Trend" while the SR monitor was considered "Qualified". Even though the IR monitor was rated as "Trend" it still gave a reasonable representation of the shape of the neutron flux during the accident.

Uncertainties for the SR monitor data are determined from Table 2 at any time by substituting the reading in counts per second into the equation. The count rate reading plus and minus the calculated uncertainty value give the upper and lower uncertainty limits at that point. There is about a 95% confidence that the true value lays within these uncertainty limits, however, this is not a truely statistical value since it contains estimates of bias. That this confidence level is near 95% is based on the method of determining total uncertainty as developed in References 1, 2, and 3.

The uncertainty in the time base of data taken from the stripcharts was estimated by comparing (1) the time difference between the occurrence of major events on the three digitized SR/IR curves, (2) the time difference between the occurrence of major events on the digitized curves and on the reactimeter timed events. The uncertainties in the time base of the SR/IR data in Table 2 include the error due to the slow response time of the measurement channel electronics (approximately 30 seconds) and the errors noted between timing of major events in the SR/IR data. There was less uncertainty in the data taken from the computer periodic log because these data did not have to be digitized from stripcharts and therefore had only the errors due to instrument response time and computer readout time.

TABLE 2

Neutron Flux Monitor Data Qualification and Uncertainty

Measurement Identifier	Quality Classification	Amplitude* Uncertainty Counts per S	Time Uncertainty (Seconds)
NI-ND-1S	Qualified	$\pm[8\times10^{-4}\times\text{Reading}+10^{6}]^{1/2}$	+10 to -45
NI-ND-1P	Qualified	"	0 to -30
NI-ND-2P	Qualified	"	0 to -30
NI-ND-3S	Trend	-------	+10 to -45
NI-ND-3P	Trend	-------	0 to -30
NI-ND-4S	Trend	-------	+10 to -45
NI-ND-4P	Trend	-------	0 to -30

*Reading is the counts per second at point of interest. Uncertainty is at the 95% confidence level.

SUMMARY

The source range (SR) and intermediate range (IR) neutron flux monitor data recorded during the TMI-2 accident are the subject of this report. These data were recorded on TMI-2 pen stripchart recorders No. 128 and No. 66 as well as on the plant computer printouts. Copies of microfiche film of original data and copies of plant computer printouts were used as the data sources for this work. The stripcharts curves for the SR monitor NI-1 and the IR monitors NI-3 and NI-4 were digitized. The data for SR monitors NI-1 and NI-2 were taken from the hourly periodic log printouts, which is the only known source of data for the SR monitor NI-2.

Corrections were made to the data where necessary, both on the time base and on the amplitude. The amplitude as recorded on the plant computer appeared to be the most accurate, therefore, the amplitudes of the digitized data were adjusted to the computer values. The time bases of both the digitized and computer printout data were adjusted to a base whose zero time corresponded to the turbine trip time of 04:00:37.

An uncertainty analysis was made on the neutron monitor measurement channels based on the way the data were being used, i.e., as a measurement of the relative neutron flux. That the monitors were designed to record relative flux was manifested by the fact that their respective readouts were in counts per second and amperes with no allowances for operator conversion into neutron flux units.

The quality classification of the data was established. The IR monitors data were classified as "Trend" because of their high uncertainties due to the fact they were operating at the lower end of their operating range. The SR monitor data were classified as "Qualified" and had a 7 to 9% uncertainty at the peak counts per second reading. The uncertainties in the time bases were determined to be +10 to -45 seconds for both the SR(NI-1) data and IR (NI-3 and NI-4) data digitized from the stripcharts.

The data were put in the TMI-2 DATA BASE accompanied by their quality classification and uncertainties.

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APPENDIX A

UNCERTAINTY ANALYSIS

The usefulness of any data obtained by measurement of physical phenomena is a direct function of the knowledge of the accuracy of the data. The data from the TMI-2 SR and IR neutron flux monitors are to be used to understand the physical phenomena which occurred in the reactor core and to perform numerous types of analyses. An uncertainty analysis was performed on the SR and IR monitor data using a generally accepted formal method. The uncertainty analysis consisted of listing all the potential sources of measurement error, calculating or estimating the amount of error, combining the elemental errors using the root-sum-square method, and then combining these errors to determine the total uncertainty.

Uncertainty is a description of the numerical bounds of a measurement error, and the true value of a measurement is predicted with some confidence to lay within these bounds. Uncertainty is an arbitrary substitute for a statistical confidence interval and can be interpreted as the largest expected error. The confidence level of the TMI-2 data uncertainty is near 95% as a result of the method used to calculate the total uncertainty. The uncertainty analysis provided the numerical error bounds of the data.

Tables A-1 and A-2 list the potential sources of error, as well as the estimated and calculated errors for the SR and IR monitor circuit components. Following the table are calculations of the total uncertainties for each monitor at the peak value observed during the accident. All the uncertainties are determined for the 95% confidence level.

Both the SR and IR monitors were used in practice to indicate relative neutron flux, reading out in counts per second and amperes, respectively. The uncertainty analysis, therefore, treated these monitors as relative neutron flux indicators which eliminated the uncertainties due to converting counts per second or amperes to absolute reactor neutron flux. It also eliminated error from such items as long term detector sensitivity drift and electronic long term drift.

The uncertainty analysis shows that the uncertainty in the SR monitor data at the peak accident value was about 7% when read from the computer and 9.3% from the stripchart. The analysis of the IR monitor measurement channel shows that the uncertainty is so high that the readings have no value even in a relative sense and therefore represent only the trend of neutron flux in the reactor during the accident. It appears that the value of the IR monitor data is in its representation of the general shape of the neutron flux curve and the timing of plant events.

Because the SR and IR data were digitized from microfiche of strip charts, there were potential errors in the time base of the reconstituted curves. Comparisons were made between the timing of major events on the digitized curves and the established times of these events in the accident sequence of events as well as the response of the power range monitor NI-5 which was recorded on the reactimeter. An estimate was then made of the uncertainty likely to be in the digitized data time bases. The estimates have about a 95% confidence level and are +10 to -45 seconds for the stripchart data and 0 to -30 seconds for the computer data. These numbers include 30 seconds attributed to the instrument response time.

TABLE A-1

UNCERTAINTY ANALYSIS

Source Range Neutron Flux Monitor

Component	Error: Random (S)	Error: Bias (B)
High Voltage Power Supply		.02 Reading
Low Voltage Power Supply	.0023 Reading	
Preamp Gain Stability		.02 Reading
Amp Repeatability		.001 Range
Recorder Repeatability	.01 Reading	
Stripchart Interpretation	.03 Reading	
Computer Readout	.001 Reading	
Computer Repeatability	.001 Reading	

Rd = reading or magnitude of the measurement in counts per seconds.

Range = 10^6 counts per second.

Total uncertainty = $U_{CT} = [B^2 + 4S^2]^{1/2}$ counts per second.

Uncertainty in reading from the stripchart record (i.e., digitized data) at the peak reading of 16K counts per second is:

$$U_{CT} = [4.8 \times 10^{-3}(Rd)^2 + 10^6]^{1/2} \text{ or } 9.3\%.$$

Uncertainty in reading from the computer printout at the peak reading 16K counts per second is:

$$U_{CT} = [8.29 \times 10^{-4}(Rd)^2 + 10^6]^{1/2} \text{ or } 6.9\%$$

TABLE A-2

UNCERTAINTY ANALYSIS

Intermediate Range Monitor

Component	Error: Random (S)	Error: Bias (B)
High Voltage Power Supply		.02 Reading
Gamma Sensitivity	.02 Reading	
Amplifier Repeatability		.001 Range
Recorder Repeatability	.01 Reading	
Stripchart Interpretation	.03 Reading	
Computer Readout	.01 Reading	
Computer Repeatability	.001 Reading	

Rd = reading or magnitude of the measurement in amperes.

Range = 10^{-3} amperes.

Total uncertainty = $U_{CT} = [B^2 + 4S^2]^{1/2}$ amperes.

Uncertainty in reading from the computer printout at the peak reading of 1.2 x 10^{-6} amperes is:

$U_{CT} = [9 \times 10^{-4}(Rd)^2 + 1 \times 10^{-12}]^{1/2}$ or 1.0×10^{-6} amperes.