BNWL-1575
~~Special Distribution~~

Battelle

Pacific Northwest Laboratories
Richland, Washington 99352

AEC Research and Development Report

THE DESIGN, TESTING AND
SPECIFICATIONS OF A SPENT FUEL
MONITOR FOR NPD REACTOR

A.D. VAUGHN

May 1971

BNWL-1575

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately-owned rights.

PACIFIC NORTHWEST LABORATORY

operated by

BATTELLE

for the

U.S. ATOMIC ENERGY COMMISSION

Under Contract AT(45-1)-1830

Printed in the United States of America

Available from

National Technical Information Service

U.S. Department of Commerce

5285 Port Royal Road

Springfield, Virginia 22151

Price: Printed Copy \$3.00; Microfiche \$0.95

3 3679 00061 8019

BNWL-1575

~~Special Distribution~~

THE DESIGN, TESTING AND SPECIFICATIONS OF A
SPENT FUEL MONITOR FOR NPD REACTOR

A Report of Work Performed Under Program TRUST - Phase I

A. D. Vaughn

May 1971

BATTELLE
PACIFIC NORTHWEST LABORATORIES
RICHLAND, WASHINGTON 99352

TABLE OF CONTENTS

Introduction	1
Summary	1
Discussion	2
A. Program Summary	2
B. Spectrometer Systems for K Reactor Experiment . .	2
C. Summary of K Reactor Experiment	3
1. Fuel Elements	3
2. Measurement Program	6
3. Data Analysis	6
4. Results of K Reactor Experiment	10
5. Cooling Times Greater than 90 Days	13
D. Analytical Determination of Feasibility of Similar Measurements for NPD Fuel	15
E. Specifications for Age Monitoring System for NPD Reactor	18
1. List of Equipment and Costs	18
2. Operating Procedures	20
3. Data Analysis	24
4. Automatic System	25

LIST OF FIGURES

Figure 1	High Resolution Detector and Instrument System	5
Figure 2	Low Resolution Detector and Instrument System	6
Figure 3	Gamma Ray Photo Peak Spectra from K Reactor Fuel Element	7
Figure 4	Peaks and Plateau Integration Limits for Low Resolution Detector Data	8
Figure 5	Ratios of Gamma Ray Photo Peaks and Plateaus	12
Figure 6	Gamma Ray Spectra at Different Cooling Times	14
Figure 7	Calculated Ratios of Gamma Ray Photo Peaks Emitted by NPD Reactor Fuel vs. Time After Shutdown	19
Figure 8	Sodium Iodide Detector and Instrument System for NPD Reactor	21

LIST OF TABLES

Table I	Integration Limits for Counting Data	9
Table II	Low Resolution Detector Data Analysis - 36 Days After Discharge	11
Table III	Channel Position Data for NPD Fuel Bundle	16
Table IV	Channel Power Data for NPD Fuel Bundle	17
Table V	Estimated Costs for Electronics Systems	22

INTRODUCTION

One objective of Program TRUST is to develop a gamma ray sensitive device to measure the age of spent reactor fuel. Therefore, a gamma ray spectrometer system was designed, assembled, and installed at the spent fuel storage basin of the KE Reactor in December 1970 by Battelle-Northwest. A test program was carried out using spent fuel from KE Reactor to derive a technique which will determine the age of the fuel (time after discharge) by the measurement of gamma ray photo peaks from fission product isotopes. This is a report of the measurement program and the successful development of a fuel age monitoring system which is intended for use at NPD Reactor, Deep River, Ontario.

SUMMARY

The spent fuel monitoring system which was tested at the spent fuel basin of the KE Reactor has been able to measure the age of the fuel irradiated at KE Reactor between ten and ninety days after discharge within a statistical uncertainty of $\pm$ three days.

The system has been designed so that a low resolution sodium iodide detector with stabilizer and five single channel analyzers provide sufficient data to determine the age of the spent fuel. The count data from the single channel analyzers are processed manually to determine the age of the fuel. The manual process involves taking the ratio of specific scaler data and determining the age of the fuel which corresponds to the measured ratio from a prepared graph.

The system is adaptable to automatic data analysis by computers if it becomes desirable to do this at a later date; however, the original objective did not include that step in the system design.

DISCUSSION

A. Program Summary

The development of an age monitor for spent reactor fuel essentially included three distinct projects: (1) the design and fabrication of a collimating device, with associated electronic equipment from on-shelf items at Pacific Northwest Laboratory, and installation of the system at KE Reactor for testing; (2) the planning and carrying out of a measurement program using spent reactor fuel irradiated at KE Reactor and data analysis methods which would determine the age of spent reactor fuel; (3) the specification and assembly of a spectrometer system using a sodium iodide detector which will be adequate for age measurements at NPD Reactor, Deep River, Ontario.

B. Spectrometer System for K Reactor Equipment

A Ge-Li spectrometer system was originally installed in the spent fuel basin at KE Reactor for two reasons, high resolution measurements were desirable to better define the gamma ray photo peaks, and the experiment offered an excellent opportunity to measure selected fuel pieces having known exposure histories.

The high resolution system is depicted in Figure 1 and consists primarily of a collimating device with variable aperture, lithium drifted germanium detector, and a 4096 channel analyzer.

The low resolution detector system is depicted in Figure 2, and consists of the same collimating device with a sodium iodide detector. Single channel analyzers were used in conjunction with scalars, as well as the 4096 channel analyzer, for data collection. The output systems, paper tape punch and a teletypewriter, were the same in both cases.

C. Summary of K Reactor Experiment

1. Fuel Elements

The neutron flux in the K Reactor follows a cosine shape axially along the fuel channel so that a fairly wide range of exposures are achieved in a single column of fuel. One channel near the radial center of the reactor was retained past two normal discharge cycles and then individually discharged piece by piece and picked up for this experiment.

Eight fuel elements were selected to provide the widest possible range of exposures. The relative exposures of the eight elements, normalized to the highest exposure element, are listed in increasing order: 0.123, 0.334, 0.543, 0.707, 0.841, 0.870, 0.986, and 1.000.

FIGURE 1. HIGH RESOLUTION DETECTOR AND INSTRUMENT SYSTEM

FIGURE 2. LOW RESOLUTION DETECTOR AND INSTRUMENT SYSTEM

2. Measurement Program

The experimental program included measurements of the gamma ray photo peaks between 400 Kev and 2500 Kev for all eight fuel elements taken on a weekly schedule with the high resolution detector and 2048 channels of the analyzer and with the low resolution detector using 512 channels of the analyzer.

The data were transferred to the paper punch tape, transferred to magnetic tape, and analyzed on the UNIVAC 1108 computer using locally developed codes, PTAC, to print and plot the number of counts per channel and SPCTR, to integrate the counts in the various peaks chosen for the data sets. A sample plot of the data obtained using both detector systems is shown in Figure 3 and the fission product photo peaks of interest to the age measurements are noted.

3. Data Analysis

The spectrometer data were analyzed by integrating the counts included in specific photo peaks measured by the low resolution detector system. The integration boundaries for the channels of interest are depicted in Figure 4 and listed in Table I.

FIGURE 3. GAMMA RAY PHOTO PEAK SPECTRA FROM REACTOR FUEL ELEMENT

FIGURE 4. PEAK AND PLATEAU INTEGRATION LIMITS FOR LOW RESOLUTION DETECTOR DATA

TABLE I

INTEGRATION LIMITS FOR COUNTING DATA

Area Designator	Start Channel	Stop Channel	Photo Peak Identification
Peak 1	96	144	^{140}La (487 Kev) ^{103}Ru (500 Kev)
Peak 2	150	192	^{95}Zr (750 Kev) ^{95}Nb (765 Kev)
Peak 3	324	390	^{140}La (1600 Kev)
Plateau 1	48	96	None
Plateau 2	240	276	None

A sample set of data is presented in Table II, as obtained with the sodium iodide detector and 512 channel analyzer. The results presented in Table II were obtained by two slightly different methods of analysis: (1) the peak ratios calculated with backgrounds and underlying continuum subtracted from the peaks, and (2) peak ratios calculated with the sum of the integrated channels, with backgrounds and continuum included.

4. Results of K Reactor Experiment

The results of the K Reactor experiment are best shown by graphs of the three ratios as a function of the time after fuel discharge, as depicted in Figure 5. The accuracy with which the fuel age can be determined is indicated by examining the spread in each ratio as measured from fuel elements having exposures that differ by about the factor of eight. One can see that the time after shutdown for the fuel from the K Reactor can be determined for each fuel piece to within two or three days over a measurement interval of ten to ninety days, based on the expected standard deviation for a single measurement and the slope of the curve of activity ratio versus cooling time.

TABLE II

LOW RESOLUTION DETECTOR DATA ANALYSIS - 36 DAYS AFTER DISCHARGE

Element Number	Spectrum Number	Date Set Date	Peak 1 No. 1 La-140	Peak 2 No. 2 Zr-95	Peak 3 No. 3 La-140	Plateau 1 No. 4	Plateau 2 No. 5
Integrated Counts (Background Corrected)							
1	54	1/4	327604	722566	120093	983036	102093
5	55	1/5	866212	1784469	293381	2452178	253483
10	56	1/5	1117787	2231017	368388	3102795	321187
15	67	1/5	1920499	3658702	600139	5168561	549609
20	58	1/5	2048339	3864210	650594	5477390	598638
23	59	1/5	1725337	3375272	567205	4724375	512197
26	60	1/5	1645865	3219381	546811	4512886	487398
29	61	1/5	1187428	2428061	405315	3343071	352039
Ratio of Data Sets				1/2	3/2	5/4	
	54			0.453	0.166	0.104	
	55			0.485	0.164	0.104	
	56			0.501	0.165	0.103	
	57			0.524	0.164	0.106	
	58			0.530	0.168	0.109	
	59			0.511	0.168	0.108	
	60			0.511	0.169	0.108	
	61			0.489	0.166	0.105	
Integrated Counts Without Background Subtracted							
	54		1095287	1116575	179254		
	55		278584	2790798	443662		
	56		3040102	3550520	938288		
	57		5959520	5832825	1014203		
	58		6324520	6152627	873462		
	59		5411558	5336545	832365		
	60		5158920	5054148	612948		
	61		3791239	3791634	---		
Ratio of Data Sets			1/2		3/2		
	54		0.900		0.161		
	55		0.995		0.159		
	56		0.997		0.159		
	57		1.022		0.160		
	58		1.028		0.164		
	59		1.014		0.164		
	60		1.021		0.164		
	61		1.000		0.161

FIGURE 5. RATIOS OF GAMMA RAY PHOTO PEAKS AND PLATEAUS

5. Cooling Time Greater than Ninety Days

The results presented in Figure 5 demonstrate the capability of the equipment to determine fuel cooling times of between 7 and ninety days, as required by the original system specifications. Calculational studies were carried out using the computer program DRAFT⁽¹⁾ to examine other fission product activities that might be useful for longer cooling time determinations. One good candidate was found to be the $^{144}\text{Ce} - ^{144}\text{Pr}$ photopeak at 2186 Kev, which, when ratioed with the $^{95}\text{Zr} - ^{95}\text{Nb}$ peak, provided a cooling time parameter that varied much more slowly than did the $^{140}\text{La}/^{95}\text{Zr} - ^{95}\text{Nb}$ ratio shown in Figure 5.

An examination of gamma ray energy spectra taken at cooling times of ~ 20 , ~ 60 , and ~ 90 days respectively, presented in Figure 6, showed that the $^{144}\text{Ce} - ^{144}\text{Pr}$ photo peak was just becoming visible by 90 days. Counting statistics for that peak were very poor, and a reliable result was not extractable from the data available. Schedule commitments which required shipment of the complete system to NPD reactor by early April precluded any further experimental study of the $^{144}\text{Ce} - ^{144}\text{Pr}/^{95}\text{Zr} - ^{95}\text{Nb}$ ratio for use as a long cooling time indicator. Calculational results predict that this ratio would be very useful for determining cooling times greater than ninety days.

⁽¹⁾ G. D. Seybold, Program DRAFT, unpublished data.

FIGURE 6. GAMMA-RAY SPECTRA At DIFFERENT COOLING TIME

D. Analytical Determination of Similar Measurements for
NPD Fuel

Part of the initial program to develop an age measurement included an analytical determination of the type of gamma ray photo peak which can be expected from NPD Reactor fuel which is moved through a cosine shaped flux profile during its irradiation history.

The analytical calculations was accomplished with program DRAFT which calculates the buildup of specific fission product isotopes as a function of the reactor parameters, namely flux and operating history, and the isotope parameters including yield, absorption cross section, and decay rates.

The DRAFT program was used to calculate the buildup and decay of isotopes ^{140}La , ^{95}Zr , and ^{144}Ce because these are the major contributors to the measurement to determine the age of the fuel.

The irradiation history is for fuel bundle 1716 which was irradiated in channel G04 in the central region of the core. The time in full power days and the level of irradiation at which the fuel bundle shifts took place are listed in Table III. Values of full power days, irradiation, bundle power and cell average thermal flux at various times during the irradiation are listed in Table IV.

TABLE III

CHANNEL POSITION DATA FOR NPD FUEL BUNDLE

Channel Position Shifts	Full Power Days In Position	Full Power Days In Channel	Irradiation n/kb
1 → 2	46.53	46.53	0.043
2 → 3	104.01	150.54	~0.25
3 → 4	81.13	231.67	~0.48
4 → 5	107.89	339.56	~0.86
5 → 6	86.81	426.37	~1.17
6 → 7	47.73	474.10	~1.32
7 → 8	112.32	586.42	~1.56
8 → 9	143.22	729.64	~1.73
9 → out	107.81	837.45	1.75

TABLE IV

CHANNEL POWER DATA FOR NPD FUEL BUNDLE

Channel Position	Full Power Days In Channel	Irradiation n/kb	Bundle Power KW	Thermal Flux $\times 10^{-13}$ n/cm ² s
2	123.38	0.177	91.9	4.05
3	172.46	0.300	144.2	6.35
4	308.88	0.761	192.1	7.62
5	374.79	1.000	165.3	7.64
6	433.20	1.210	135.5	6.39
7	492.89	1.374	92.7	4.45
8	611.55	1.601	45.0	2.20
8	720.18	1.731	57.1	2.83

The analytical results are presented in terms of the ratio of the ^{140}La to ^{95}Zr decay rate and the ratio of ^{95}Zr to ^{144}Ce decay rate with respect to the time after discharge from the reactor, in Figure 7. The results of the calculations indicate that the fission product decay of these specific isotopes at the NPD Reactor should provide adequate data with which to determine the age of the fuel. There is sufficient saturation of these fission product isotopes, when in the relatively low flux position just prior to discharge, that the age of the fuel should be determinable by a method similar to that which was demonstrated for the K Reactor fuel.

E. Specifications for Age Monitoring System for NPD Reactor

1. List of Equipment

The criteria for a fuel age monitoring device for NPD reactor are:

- Sodium Iodide detector system
- Relatively simple to operate
- Will determine age of the spent fuel
- Equipment installed at NPD Reactor during April, 1971.

FIGURE 7. CALCULATED RATIOS OF GAMMA RAY PHOTO PEAKS EMITTED BY NPD REACTOR FUEL VS TIME AFTER SHUTDOWN

The equipment necessary to meet these specifications has been assembled and is illustrated in Figure 8. The system includes the collimator from KE Reactor, five single channel analyzers with scalers and a sodium iodide detector doped with ^{241}Am to provide a 3 Mev peak for operating the system gain stabilizer. A multi-channel analyzer can be added to assist in the calibration of the single channel analyzers or to replace the single channel analyzers if an automatic read out and data handling system is preferred.

The estimated costs of purchasing the electronics package for (1) the basic single channel analyzer type system, and for (2) an automatic computer based system, are listed in Table V. The basic system requires the operator to read the scalers, calculate the ratios and infer the fuel age from a family of curves. The automatic system could be readily programmed to perform the necessary calculations and to present the inferred value of fuel age with no additional interaction with the operator.

2. Operating Procedures

The operating procedures for the basic system equipment are:

FIGURE 8. SODIUM IODIDE DETECTOR AND INSTRUMENT SYSTEM FOR NPD REACTOR

TABLE V

ESTIMATED COSTS FOR ELECTRONICS SYSTEM

<u>Multichannel Analyzer System</u>		<u>Single Channel Analyzer System</u>	
Multichannel Analyzer - Computer Assembly	\$13,500	2 Instrument Bins	\$1,100
NIM Bin	500	HV Power Supply	460
High Voltage Power Supply	460	Analog Stabilizer	850
Analog Stabilizer	850	Amplifier	450
Amplifier	450	Preamplifier	115
Preamplifier	115	Detector	500
Miscellaneous Cables, etc.	100	5 scalers	3,400
Total	\$16,525	5 Single Channel Analyzers	1,200
		1 Timer Scaler	900
		Total	\$9,175

- a. Use ^{137}Cs source (662 Kev) and ^{60}Co source (1173 Kev and 1332 Kev) to calibrate the Multi-channel analyzer.
- b. Use coincidence circuit in Multi-channel analyzer to calibrate single channel analyzers to channel widths as listed,
 - Channel 1 429 Kev to 644 Kev
 - Channel 2 670 Kev to 858 Kev
 - Channel 3 1450 Kev to 1740 Kev
 - Channel 4 214 Kev to 429 Kev
 - Channel 5 1072 Kev to 1233 Kev
- c. Place fuel element on spectrometer tray, lift tray under spectrometer window and lock in position.
- d. Start clock and counting system.
- e. Write down scaler data for each fuel piece counted when counters shut off.
- f. Calculate ratios, compare with curves to determine age.
- g. Exchange fuel, reset counters, and start counting.

3. Data Analysis

For the single channel readout devices the integrated peaks from each scaler can be listed on a data sheet until they can be ratioed by a manual calculator. The ratios must then be compared to a set of previously prepared graphs to determine the fuel age.

The graphs for the NPD fuel will have to be made from a controlled data experiment conducted on the NPD fuel similar to the K Reactor experiment.

If a multichannel analyzer system is preferable, data similar to the single channel data can be obtained by training an inspector to operate the analyzer so that the proper channels are summed by the integration circuit on the analyzer. After the sums are obtained, the procedures of taking ratios and comparing the graphs are exactly the same.

4. Automatic System

It is possible to make the data handling system completely automatic by the purchase of prearranged and programmed data handling circuits with the analyzer when it is ordered. These additional services are provided at extra cost but are relatively simple to add to the computer circuit of the analyzer. Such a system is recommended as very desirable to provide a consistent analysis method, uninfluenced by operator bias or error. The amount of training required to operate the system would be minimized.

DISTRIBUTION

Number of Copies

OFFSITE

3	<u>US Arms Control and Disarmament Agency</u> F. S. Houck R. R. Rentschler L. R. Stieff
3	<u>AEC Division of Technical Information Extension</u>
5	<u>AEC Office of Safeguards and Materials Management</u> W. C. Bartels Gen. D. L. Crowson G. M. Inman S. C. T. McDowell J. M. Williams
3	<u>Brookhaven National Laboratory</u> H. C. Kouts W. A. Higinbotham C. A. Sastre
3	<u>Atomic Energy Control Board</u> P. O. Box 1046 Ottawa, Canada J. C. McManus
1	<u>Ontario Hydro</u> NPD Generating Station Deep River, Ontario, Canada R. S. Cecil

Number of Copies

OFFSITE

- 1 Atomic Energy of Canada, Ltd.
Chalk River
Ontario, Canada
J. B. Ogg
- 3 International Atomic Energy Agency
Karntner Ring 11
A-1010 Vienna, Austria
A. J. Walligura

ONSITE - HANFORD

- 1 AEC Chicago Patent Group
K. M. Poteat
- 5 RDT Assistant Director for Pacific Northwest Programs
W. E. Fry
P. G. Holsted
H. A. House
J. B. Kitchen
T. A. Nemzek
- 2 AEC Richland Operations Office
M. R. Schneller
- 21 Battelle Northwest
C. A. Bennett
N. E. Carter
D. E. Christensen
R. A. Schneider
L. C. Schmid
R. I. Smith (10)
A. D. Vaughn
Technical Information Files (5)