AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

HANFORD CODE Q-65

DECLASSIFIED

BNWL-CC-437

**FEASIBILITY STUDY FOR PERIMETER INSPECTION
OF SHUTDOWN PRODUCTION REACTORS**

**G. C. FULLMER, D. R. GREEN,
and D. P. GRANQUIST**

FEBRUARY, 1966

PACIFIC NORTHWEST LABORATORY operated by BATTELLE MEMORIAL INSTITUTE

DECLASSIFIED

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

DECLASSIFIED

Classified by:
D. C. Worlton

BNWL-CC-437

This document consists
of 63 pages. Copy No. 1
of 1 copies. Series 1

FEASIBILITY STUDY FOR PERIMETER INSPECTION
OF SHUTDOWN PRODUCTION REACTORS

By

G. C. Fullmer, D. R. Green,
and D. P. Granquist

February, 1966

Classification Cancelled and Changed To

DECLASSIFIED

By Authority of CG PR-2

DS Lewis 2-11-94

By Perri Moley 2-15-94

Verified By J. E. Sack 2-22-94

This document contains Restricted Data as defined by the Atomic
Energy Act of 1954. Its transmittal or disclosure of its con-
tent in any manner to an unauthorized person is prohibited.

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON

Route to:	P.R. No.	Location	Route Date	Signature and Date
<u>300 & 10</u>				

DECLASSIFIED

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION	4
SUMMARY	6
DETAILS	11
I. Bases	12
II. Field Testing	14
A. Neutron and Gamma Measurements	14
1. Neutron Measurements	16
2. Gamma Measurements	16
B. Infrared Measurements	24
1. Equipment	25
2. Heat Flow Theory	28
3. Experimental Measurements	32
III. Discussion.	48
A. Applicability to Other Reactor Designs and Environ	49
1. Nuclear Radiation	49
2. Infrared Radiation	52
3. Potential Countermeasures	54
4. "Black Box" Detection	55
B. Consideration of Alternate Criteria	56
IV. Acknowledgements	59
APPENDIX - Ground Rules	60

LIST OF FIGURES

<u>Figure</u>	<u>Title</u>	<u>Page</u>
1	Neutron and Gamma Detection Equipment	15
2	Typical Gamma Spectra Readout	19
3	Gamma Spectra Readout-Behind B Reactor	21
4	Gamma Spectra Readout-B Reactor, Hanford, 300 Area	22
5	Infrared Radiometer in Field Use	26
6	Calculated Reactor Wall Temperatures	30
7	KE Wall Temperatures	33
8	KE Wall Temperatures	34
9	KE and KW Wall Temperatures	36
10	Surface Temperatures Near KE Effluent Line	37
11	Surface Temperatures Near KE Effluent Line	38
12	KE and KW Effluent Basin Temperatures	39
13	Taking Infrared Data at D Reactor	40
14	"Nearside" and Rear Views of D Reactor	42
15	D and DR Wall Temperatures	43
16	D and DR Wall Temperatures	44
17	D and DR Wall Temperatures	45
18	D and DR Wall Temperatures	46
19	Surface Temperatures Near D Effluent Line	48

LIST OF TABLES

I	Neutron Counting Data	17
II	Gamma Counting Data	20
III	Infrared Readout and Calculational Data	28
IV	Calculated Ground Surface Temperatures	31

FEASIBILITY STUDY OF PERIMETER INSPECTION
FOR SHUTDOWN PRODUCTION REACTORS

INTRODUCTION

Administrative Background

In fulfillment of a request by the Atomic Energy Commission, an inspection system was developed by the Hanford Atomic Products Operation of General Electric Company during 1964 for periodic monitoring of production reactors should they be shut down under international agreement. Ground rules included access to the reactor building and to the reactor core itself for installation, checking, and removal of equipment for determining whether or not the reactor had been operated between periodic inspection visits. "Safing" wire and seals were developed with randomness inherent in their fabrication for revealing attempts to remove neutron-detecting materials, and a report was prepared describing the technical bases for the system and providing detailed instructions for its application.^(1, 2)

Subsequent correspondence from the Atomic Energy Commission⁽³⁾ indicated that the in-core system proposed was satisfactory for the ground rules under which it was developed, but that the Arms Control and Disarmament Agency wished also to know whether or not a perimeter inspection system would be feasible. For purposes of this study "perimeter" access at a radius of one mile was to be assumed. Hanford was asked to investigate and report on the feasibility of such a system, the extent of work to be equivalent to a Title I design effort.

-
- (1) RL-REA-26, "Reactor Shutdown Inspection System - Technical Development and Evaluation," Staff of Hanford Atomic Products Operation, November 25, 1964 (Confidential).
 - (2) RL-REA-26-APP, "Systems Manual - International Monitoring of Shutdown Production Reactors," November 25, 1964 (Official Use Only).
 - (3) "Investigation and Report on the Feasibility of a Perimeter Inspection System for Determining if a Reactor Remains Shutdown," A. T. Gifford to A. B. Greninger, May 10, 1965.

DECLASSIFIED

- 5 -

BNV L-CC-41

This report describes the work carried out by Battelle-Northwest on this program. Administration and funding for the program were arranged between the Production Reactor Division of the Richland Operations Office of the Atomic Energy Commission, and the General Electric Company's Irradiation Processing Department, subsequently transferred to Douglas-United Nuclear.

Technical Background

Many methods are available for indicating from a distance the existence and operation of a nuclear reactor facility. Circumstantial evidence is provided by such items as worker entry and activity, power consumption, material arrival and shipment, and by the character of the materials and the skills of the individuals involved. Activity of this nature may be monitored by visual and aural means by an individual observer, or may be recorded utilizing photographic, sonic, electromagnetic, or other well established techniques. Although evidence of a circumstantial nature is useful for intelligence purposes, it could be highly controversial for purposes of establishing whether or not a production reactor shutdown agreement had been violated.

The specific trademark of nuclear reactors is the production of an extremely great amount of gamma and neutron radiation during the process, and a lesser but still significant amount of residual radioactivity which remains after the reactor has been shut down. Because the reactor buildings are designed to permit worker access during their operation, the amount of radioactivity from the reactor core which penetrates the shielding is very low. Activation of the reactor coolant or unintentional escape of activation products with reactor effluents could also indicate reactor operation, specific trademarks being associated with specific reactor types, such as N^{16} with water coolant, A^{41} with air coolant, and H^3 with D_2O coolant.

A less specific but notable characteristic of reactor operation is the tremendous amount of heat produced. Knowledge of both the flow and the temperature rise of the reactor coolant would reveal the production rate. Flow can be inferred, but not monitored directly at perimeter distances,

DECLASSIFIED

- 6 -

BNW

by such indications as power consumption, pump noise, or river turbulence. Temperature rise may easily be observed at perimeter distance with infrared equipment but direct relations between temperature rise and heat production rate must be established if infrared data are to be used for verifying reactor shutdown.

SUMMARY

A system for monitoring a reactor shutdown agreement from the fenced perimeter, up to a mile away, would impose the following requirements and limitations in establishing its feasibility.

1. Instrument indications would at best give an indication of whether the reactor was operating or not operating at the time of monitoring. They would not of themselves indicate the absolute power level.
2. Assuming that the monitored reactor was shut down prior to an inspection visit and that another reactor in the locale was operating legitimately, data obtained during an inspection visit would not reveal whether or not the monitored reactor had been operated between inspection visits.
3. Perimeter inspection as a shutdown monitoring method should therefore be continuous or nearly continuous, either by resident personnel or by a "black box" system.
4. Instrumentation and packaging requirements for a "black box" monitor to be left in place for extended intervals between inspection visits would require component reliability, criteria development, and counter-measure protection comparable in sophistication to that demanded for space mission systems.
5. Considering the present state of developed equipment it is concluded that perimeter inspection should be considered only if agreement is obtained for resident observers, either with 24 hr coverage or random access on any day with up to 1 hr notice.

DECLASSIFIED

BNW MCC-48

More specific conclusions relating to ground rules supplied for the study are given in the following paragraphs entitled "One-Mile Perimeter" and "One-Tenth-Mile Perimeter." In assessing these conclusions the previous five points should be kept in mind, in particular that perimeter information relates to instantaneous rather than integrated operating status.

One-Mile Perimeter

A. Feasibility

Assuming that buildings and utilities within the area could legitimately be used for other processes, it would be almost impossible to positively substantiate that the observed reactor was operating or shutdown. Experimental results at Hanford indicate that no neutrons would be detected at that distance and that reactor-originated gamma activity would be less at one mile than normal background variations. Although temperatures of the reactor building and other facilities could be determined with infrared monitoring, alternate processes or simple countermeasures would invalidate normally expected relations between observed temperatures and status of reactor operation. The presence of a resident observer could, however, have merit if he had continuous or near-continuous random access completely around the perimeter.

B. System

No system is proposed on the basis of one-mile perimeter access.

One-Tenth-Mile Perimeter

A. Feasibility

There is a reasonable chance that reactor operation could be determined by a resident observer or observer team with 24 hr or near-continuous random access to a one-tenth-mile perimeter. Test results on Hanford reactors indicated that neutrons could probably be observed on the order of one-eighth mile, high energy gammas on the order of one-half mile, and infrared from up to several miles from the reactor. Because of differences in reactor types and potential attenuation and/or distortion due to countermeasures, specific methods for obtaining and correlating data would have to be worked out in part by the observer's continuing field checks for non-random variations.

DECLASSIFIED

-8-

BN

B. System

The field observer, or team of observers, should have a pickup truck and radiation detection and analyzing equipment for neutron, gamma, and infrared radiation of comparable or superior sophistication and quality to that employed in the experiments, namely:

- A portable gasoline generator, 115 Vac.
- Neutron chambers and scaler, with moderator sleeves and cadmium sheet available
- Gamma analyzer, oscilloscope with camera, and electric typewriter. Calibration gamma sources should also be available.
- Infrared Radiometer of high resolution
- A 5 in. long by 3 in. diameter NaI(Tl) gamma-detection crystal
- Approximately 500 lb of clean iron bricks
- Assorted cables, cords, and spare parts
- A second motor vehicle for personnel transportation.

The above equipment is sufficiently standard to permit utilization by qualified electronic technicians using manufacturer manuals.

C. Costs

The above equipment, including the pickup truck, can be purchased for approximately \$30,000. The greater flexibility possible with more sophisticated equipment which could permit continuous recording, scanning, etc., and which would include a desirable replacement and spare part inventory might justify an expenditure on the order of \$100,000. The cost of manpower for the observer position would be the order of \$100,000 per year for a 24 hr continuous surveillance team of four, or about \$25,000 per man for in-residence random but near-continuous coverage. This amount should cover salary, living allowance, and three or four return visits per year.

D. Schedule

The suggested components are shelf items. It should be possible to get an observer or a team of observers into the field in a month and to procure the suggested equipment within 6 months.

DECLASSIFIED

BNWL-CC-43

E. Intensity of Inspection

1. Twenty-Four Hour Coverage. Full-time monitoring would of course permit observation of all activity in the area including movement of personnel, freight, and equipment. Detection equipment could be utilized to gain statistical background data, and time would be available for systematically studying the area both within and outside the perimeter fence for disclosure of unusual activities or trends.

2. One-Hour Notice. Complete shift availability for random access to the perimeter on one-hour notice could be nearly equivalent in effectiveness to twenty-four hour perimeter presence. It is assumed that three resident personnel would be required in this case instead of the four assumed for twenty-four-hour perimeter coverage. A two-man in-resident team averaging one-shift coverage could also provide reasonable monitoring on the basis of one-hour access. With daily access for servicing and monitoring equipment, field measurements for statistical studies could be attempted over extended intervals with the use of recorders. Safing requirements for instrumentation would not appear necessary in this situation: evidence of tampering or countermeasures to compromise accuracy of recorded data could be accumulated to determine patterns of surreptitious activity.

3. Nonresident Monitoring. Perimeter inspection only on advance notice of several hours or several days is not considered adequate for the reasons stated earlier:

- (a) Inspection of a shutdown reactor from the perimeter will not reveal its operating history.
- (b) Because of the exceedingly rigorous reliability and functional requirements, a "black box" approach for recording operating history between inspections is not considered feasible at this time.

4. Flyover Permitted. Agreement for monitoring by frequent randomly timed flyovers would improve the integrity of a perimeter

DECLASSIFIED

- 10 -

BNW

inspection, especially in the nonresident case. Gamma and neutron activity could be observed from low level (<1000 ft) from vertical tolerance gaps and open coolant systems as exist at Hanford but would not be expected over the more compact closed-loop Savannah River reactors.

Infrared instruments in aircraft would have the capability of "seeing" effluent heating effects over an extended area, thus reducing the potential success of countermeasures. Heating patterns in rivers and lakes would also be much more distinguishable from the air than the ground.

The primary disadvantage of detection from aircraft, unless done by helicopter, is that monitoring and/or scanning time is so short that basic detector sensitivity has to be several orders of magnitude better than stationary sensors to achieve accuracy equivalent to that of surface data.

The preceding conclusions must be further qualified by the following considerations:

- (a) Radiation and temperature data in this report were taken only near Hanford production reactors; additional studies would be required to justify their applicability to other reactor types and to greater distances.
- (b) Despite the best in instrumentation sensitivity and reliability, perimeter data indications of violation must be regarded as circumstantial evidence rather than absolute proof, except in idealized cases.
- (c) Especially because of the possibility of countermeasures, such as additional shielding or rerouted piping, provision for a periodic simple walk-through of the reactor building would enhance the integrity of a perimeter inspection system, and of itself would be much more effective than would a nonresident perimeter inspection system.

DECLASSIFIED

-11-

BNWL

The updated experimental findings in this study generally reinforce conclusions from an earlier study⁽¹⁾ regarding positive identification of reactor operations.

DETAILS

Correspondence from the Atomic Energy Commission⁽²⁾ requested a study on the feasibility of perimeter inspection for determining whether or not a shutdown production reactor remained down. The desired study was summarized in the request as follows:

"The extent of work to be accomplished should be considered as equivalent to a Title I design effort, to include the following:
(a) an evaluation as to the feasibility of perimeter inspection,
(b) dependent upon the feasibility, an outline description of a system or systems which would accomplish the intended purpose including a description of the equipment required along with operational procedures for their use, (c) a preliminary estimate of cost, and (d) a preliminary schedule showing the time required to establish the inspection system."

Details of the work carried out in this assignment are presented in the following four sections.

- I. Bases
- II. Field Testing
- III. Discussion
- IV. Acknowledgements

(1) HW-6800, "Studies of Inspection and Control Systems--Number II," R. J. Brouns. June 1, 1960. (Secret)

(2) "Investigation and Report on the Feasibility of a Perimeter Inspection System for Determining if a Reactor Remains Shutdown," A. T. Gifford to A. B. Greninger. May 10, 1965.

DECLASSIFIED

-12-

BN

I. Bases

An appendix to the request letter from the Atomic Energy Commission contained preliminary ground rules for guidance of the perimeter inspection study. The format of those ground rules was followed in general in the summary. The specific ground rules are reproduced as an appendix to this document from Appendix A of "Investigation and Report on the Feasibility of a Perimeter Inspection System for Determining if a Reactor Remains Shutdown," A. T. Gifford to A. B. Greninger, May 10, 1965. The following paragraphs describe the characteristics of reactor operation and construction pertinent to the design and use of a perimeter-based monitoring system.

Required design characteristics of a reactor plant are illustrated by the order of magnitude of the conversion constants inherent in the chain reaction. About 1 g of U^{235} must fission per gram of plutonium produced. Employing Avagadro's number, the number of fissions in 1 g of U^{235} may be estimated:

$\frac{6 \times 10^{23} \text{ atoms}}{235 \text{ g}}$ produce $\sim 2\frac{1}{2} \times 10^{21} \frac{\text{fissions}}{\text{gram}}$, yielding on the order of 6×10^{21} neutrons and 5×10^{21} residual fission product atoms.

Converting the heat per fission (of the order of 200 MeV) to standard units yields a heat release per gram of U^{235} fissioned of the order of 20,000 kWh. Obviously, the production of many grams of plutonium per day generates tremendous amounts of radioactivity and heat which at first glance would appear quite easy to detect even at considerable distance.

The low tolerances on radioactivity for health reasons require, however, that fission products be contained, and that anything else subject to irradiation such as reactor coolants, be either contained (and shielded) or of such composition and purity that escape of appreciable radioactivity to the environs is not permitted. Thus the intended level of radioactivity emanating from the reactor complex would not add significantly to the environmental background already present. In fact, this statement would largely hold true within the reactor building itself, as it is necessary that

DECLASSIFIED

BNV L-CC-43

workers within the building not be subjected to radiation dose rates in excess of those tolerable at a continuing lifetime rate. Thus the measures taken for sensible reactor design lead to the result that differences in the radiation level of the surrounding environs due to reactor operation are small relative to the natural background already present, the magnitude of such differences being of statistical nature. Specific exceptions to this general statement may occur due to inadequate design of an entryway through a shield, inadequate purity of coolant, or leaks in seals, fuel element containers, etc. However, such exceptions can generally be isolated and overcome if they cause problems.

Removal of heat produced in the reactor is generally limited by mechanical aspects. Coolant supply must be provided such that the intended quantity of heat may be carried away within the coolant system's capacity, generally limited by the boiling point in the case of an open liquid system or by other engineering limits in the case of a pressurized closed loop or a gas-cooled system. In any event, coolant lines are generally insulated to minimize heat losses and to permit building access during operation wherever feasible. Otherwise, there has been no overriding reason to shield against the existence of high temperatures in and adjacent to effluent lines.

As indicated earlier, different types of reactors would reveal evidences of operation in different ways and in different amounts. Construction of the one-pass water-cooled Hanford production reactors is such that maximum external indications would be expected to come from the effluent water. The effluent should warm the secondary shield wall behind the rear face, the "downcomer" area into which all the flow from the rear crossheaders eventually feeds, the underground line from the downcomer to the retention basin where it stays for a short time, and finally the river itself after the warm water leaves the sunken outfall line.

Penetrating radiation from the effluent water would be expected from the 7.35 second N^{16} activity, created by an (n,p) reaction on oxygen in the reactor coolant. The 6 and 7 MeV gamma activity from the N^{16} decay

DECLASSIFIED

-14-

BN

would be expected to penetrate the reactor shield more effectively than would the bulk of lower energy radiation present in the effluent stream, and N^{16} activity would also be expected in the cloud of vapor and condensate created by the retention basin. Activation of impurities in the coolant will also induce some longer-lived activities which may be released to the environment. Although direct reactor sources of radiation might contribute to remote indications, such as "sky shine" from radiation streaming through the tolerance gap around vertical safety rod entries, it would be expected that the effluent activity would be the most significant remote indicator from a Hanford reactor.

II. Field Testing

In order to assure that survey results did indeed reflect the current state of the art, field measurements were made of the primary indicators--neutrons, gamma radiation, and temperature. Equipment utilized for these measurements was of sufficient sensitivity to permit extrapolation of results to optimum laboratory conditions, and equivalent to or better than that conceived for field use by an inspection team.

A. Neutron and Gamma Measurements

The photographs in Figure 1 show the equipment used for neutron and gamma measurements made on three different days at the B Reactor. (The adjacent C Reactor was also operating at the time the measurements were made).

Neutron-counting equipment included eight BF_3 chambers of standard design feeding in parallel a No. 49-50 RIDL scaler operating at 1250 V. This chamber has a sensitive area of $1\frac{1}{4}$ in. diameter by 9 in. length, and is filled with enriched $B^{10}F_3$ to 5 cm mercury pressure and with argon to 20 cm mercury pressure.

Moderator sleeves and cadmium sheets were also utilized. The increase in count rate due to moderation of more energetic neutrons and the decrease in count rate due to cadmium absorption of slow neutrons provides a useful qualitative indication of the true sensitivity of the chamber system.

DECLASSIFIED

-15-

BN

a. Neutron Detection and Readout Equipment

b. Gamma Detection and Analyzing Equipment

c. Taking Field Measurements

FIGURE 1

Neutron and Gamma Detection Equipment

DECLASSIFIED

-16-

BN

A 3 x 5 in. diameter NaI crystal and scintillation detector assembly, normally used for aerial Environmental Monitoring, was the gamma-sensing element. Following pre-amplification, the signal was fed into a No. 101 Nuclear Data 256-channel analyzer. Readout was available both by oscilloscope (with Polaroid attachment) and by electric typewriter.

The above equipment was powered in the field by a small motor-generator set which maintained a steady voltage at 117 to 118 Vac. All gamma readings (with exception of source calibrations) were made over 20 min intervals.

1. Neutron Measurements

Results of neutron measurements are shown in Table I. Counting times were generally of 10 min duration. The BF_3 chambers were checked individually for neutron response with a PuBe source and for nongamma response with a Co^{60} source. An N. Wood Company No. G-20-12 chamber (procured earlier at Hanford for graphite purity testing) using a high gas pressure provided a sensitivity comparable to that of the multiple assembly of standard BF_3 chambers, and it was substituted on the third day of measurements. This chamber has a diameter of 2 in., an active length of 12 in., and contains fully enriched B^{10}F_3 under 40 cm mercury pressure. The lower cadmium-covered readings with the latter chamber indicated better noise characteristics and thus improved net sensitivity. However, results of extrapolations to perimeter distances by both attenuation and inverse-square effects yielded the same conclusion in either case. Reactor-associated neutron activity at perimeter distances of 1 mile would be too small, compared to natural background, to be meaningful.

2. Gamma Measurements

Measurements taken several years previously at Hanford had indicated that gross gamma activity associated with reactor operation could not be distinguished from background at perimeter distances. Equipment was therefore assembled for this study with requirements of:

- High detection sensitivity
- Directional sensitivity
- Energy discrimination

DECLASSIFIED

BNW-CC-134

TABLE I
NEUTRON COUNTING DATA

Location	Day Performed	Average Counts per Minute			
		Unmod.	Mod.	Cadmium Unmod.	Covered Mod.
200 ft behind rear face, B Reactor	1st	74	132	14	108
1500 ft behind rear face, B Reactor	1st	15 15	14 13 13		
2600 ft behind rear face, B Reactor	1st		18 18	15	
	2nd	10 13	14 10 12	15 15 15	
750 ft to front and right* from B Reactor (in tri- angular location relative to C Reactor	3rd	14 15	28 28 36 32	2 1	
NW of Hanford Townsite* (several miles from nearest reactor and out of line of site of river surface)	3rd	2.5 3	11 10	$\sim \frac{1}{2}$	

* Using single N. Wood Company chamber in place of eight standard chambers in parallel.

DECLASSIFIED

-18-

BN

These requirements were met with the use of a 3 in. thick x 5 in. diameter NaI(Tl) crystal, a 256-channel analyzer, and a lead-brick collimator. A collimating sleeve with 2 in. of lead all around was fabricated using $\frac{3}{4}$ ton of new lead bricks. This assembly was constructed on the bed of a pickup truck, and the rear of the pickup was pointed toward or away from the reactor as desired for the specific readings. The collimating and analyzing equipment are shown as used in Figure 1b.

Two readouts of the gamma activity are available. Accumulated counts in each of the 256 channels were stored during the counting interval, and permanently recorded later by: (1) a polaroid photo of the oscilloscope display, and (2) a channel-by-channel listing typed by the electric typewriter. A typical set of data from a counting interval is shown in Figure 2. Energy calibration of the equipment was observed to remain nearly constant in checks utilizing Zn^{65} , Cs^{137} , Ba^{133} , and Co^{60} . The primary energy of interest, 6 MeV, was consistently indicated in the range of channels 150 through 160.

The spectrum photos are useful qualitative indicators. From them the low energy activity variations from day to day appear to be larger than those due to change in collimator direction. The high energy activity, on the other hand, appears to be sensitive to collimator direction; however, this indication comes from an apparent change in density of higher energy data points in the range of less than 10 counts per channel per 20 min.

The qualitative indications from the spectrum photos were verified quantitatively by reference to the typewriter readout sheets. Counts were totalled over the zero row (channels 0 through 9), and over rows 14 and 15 (channels 140 through 159) to provide sufficient counts to be statistically significant. Table II shows the results of this evaluation, in which the gamma counts in the range up to approximately 0.5 MeV, and those in the range of 6 MeV are given for different locations and collimator configurations. Spectral photos of most of the data listed in Table II are shown in Figures 3 and 4.

DECLASSIFIED

-19-

BNW 100-425

20 minute count in room 109, 3706 bldg ending 1345 29 Oct 65
1/8 in lead on sides and 1/4 in lead in front of detector

00000	09392	14042	15619	14104	13355	11670	09967	09321	08851
08193	07393	06902	05971	04762	04453	04038	03867	03623	03459
03270	03107	02735	02446	02658	02665	02368	01967	01607	01468
01451	01789	02086	02441	02244	01534	00876	00555	00473	00486
00493	00506	00463	00360	00308	00270	00258	00223	00243	00295
00267	00305	00298	00286	00248	00203	00163	00150	00161	00174
00202	00254	00297	00300	00257	00202	00144	00083	00042	00035
00037	00038	00034	00033	00035	00033	00018	00038	00030	00020
00030	00024	00022	00015	00038	00018	00032	00021	00023	00033
00016	00024	00027	00016	00027	00024	00019	00016	00016	00017
00019	00013	00010	00019	00020	00024	00017	00008	00021	00017
00019	00017	00015	00019	00015	00017	00015	00020	00021	00017
00017	00012	00005	00014	00011	00011	00010	00010	00013	00015
00010	00016	00008	00019	00017	00007	00016	00012	00019	00020
00010	00011	00012	00013	00010	00012	00011	00011	00013	00008
00009	00011	00016	00011	00010	00012	00009	00014	00010	00012
00019	00012	00008	00009	00012	00011	00014	00011	00011	00007
00007	00011	00011	00011	00011	00011	00011	00011	00011	00011
00007	00007	00007	00008	00004	00008	00007	00006	00007	00013
00005	00007	00012	00003	00007	00006	00006	00009	00003	00006
00004	00007	00008	00011	00003	00003	00006	00007	00002	00007
00010	00011	00012	00004	00004	00005	00009	00002	00011	00008
00005	00007	00004	00005	00003	00007	00007	00008	00005	00005
00001	00006	00010	00004	00007	00009	00006	00008	00006	00007
00009	00007	00005	00008	00005	00006	00003	00006	00007	00006
00006	00001	00002	00005	00005	00004				

a. Actual Count Data as Printed Out by Electric Typewriter

b. Polaroid Photo of
Oscilloscope Readout
of Same Data -
Log Count Versus
Channel

FIGURE 2

Typical Gamma Spectra Readout-Oscilloscope and Typewriter

DECLASSIFIED

-20-

BNV

TABLE II
 TWENTY MINUTE GAMMA COUNTS AT LOW ENERGY (0 to $\frac{1}{2}$ MeV)
 AND HIGH (~ 6 MeV)

Location	Day Performed	0 Through 9 Channels				140 Through 159 Channels			
		Toward Reactor		Collimator Turned		Toward Reactor		Collimator Turned	
		Collimator Normal	End Shielded	Toward Basin	Away	Collimator Normal	End Shielded	Toward Basin	Away
200 ft behind rear face, B-Reactor	1st	179,067 (3a)*		208,783 (3b)	73,398 (3c)	1,431 (3a)		4,512 (3b)	1,285 (3c)
1500 ft behind rear face, B Reactor	2nd	111,636 (3d)			105,762 (3f)	553 (3d)			186 (3f)
		102,665 (3e)				562 (3e)			
2600 ft behind rear face, B Reactor	1st	42,547 (4a)				247 (4a)			
	2nd	22,007 (4b)	26,472 (4c)		20,982 (4d)	249 (4b)	111 (4c)		113 (4d)
	3rd	21,181			23,820	237			169
750 ft front and SW from B Reactor (Triangular location relative to C Reactor)	3rd	21,278			20,329	398			171
NW of Hanford Townsite (Several miles from nearest reactor, and out of line of site of river surface)	3rd				16,309 (4e)				103 (4e)
					[305,010] (4f)**				[225] (4f)
In 300 Area	Between 2nd and 3rd days in field				[436,836] (4g)				[247] (4g)

* () Figure No. of Reference Oscilloscope Photo

** [] No shielding around crystal

DECLASSIFIED

-21-

BN

200 ft Behind Rear Face, B Reactor

1500 ft Behind Rear Face, B Reactor

(3a) Collimated, Toward Reactor

(3d) Collimated, Toward Reactor

(3b) Collimated, Toward Basin

(3e) As Above, Second Count

(3c) Collimator Aimed SE
(Away from Reactors and Basins)

(3f) Collimator Aimed SE
(Away from Reactors and Basins)

FIGURE 3

Gamma Spectra Readout—Log Scale, 256 Channels, 20 min

DECLASSIFIED

-22-

BNWL-CC-437

2600 ft Behind Rear Face, B Reactor

Background Data

(4a) Collimated, Toward Reactor

(4e) NW of Hanford Townsite
Collimator Aimed WNW

(4b) Repeat of (4a), Following Day

(4f) Same Location as (4e), but
Crystal Removed from Collimator

(4c) Same Orientation as (4b), but
2 in. Lead Over End of Collimator

(4d) Collimator Aimed SE
(Away from Reactors and Basins)

(4g) Taken with Same Equipment in
300 Area Lab. Crystal Unshielded

FIGURE 4

Gamma Spectra Readout - Log Scale
256 Channels, 20 min

DECLASSIFIED

-23-

BNWL-CC-437

The weather was fair on all three days. Vapor condensate from the retention basins, located approximately 0.3 mile to the right of the B Reactor as one faced the rear, rose nearly vertically but with some drift toward the observer, and occasionally toward the reactor. Vents in the underground effluent line which extends from the C Reactor to the retention basins and to the rear of B Reactor released a small amount of steam between the observer and the B Reactor and presumably some moisture not apparent as condensate.

The 1500 and 2600 ft data shown in Table II indicate little difference in the collimated readings toward and away from the reactor at low gamma energies but about a factor of 2 difference between toward and away readings in the 6 MeV range. The similar drop in reading when the end of the collimator was covered with lead bricks at the 2600 ft location tends to confirm the conclusion that reactor operation was "observed" at the half-mile location. The observation of an increase in low energy counts with the addition of the end shielding appears anomalous, but may be related to the discussion on neutron production in massive shields from cosmic radiation in Section III A.1.

Two other observations appear to limit the extent to which the above data may be extrapolated, however. The first is the high sensitivity to condensate in the atmosphere above the retention basins shown by the data at the 200 ft location. Activity in the 6 MeV range was more than a factor of 3 higher when the collimator "looked at" the retention basin clouds instead of the reactor. Low energy gamma activity was cut by a factor of 2 when the collimator was turned away at the 200 ft location, indicating that the reactor environs added significantly to total gamma at that distance. The high energy gamma was reduced only slightly, however, when the collimator was turned away from the reactor, again indicating that the major source of high energy activity came from the effluent basins rather than directly from the reactor building.

The second observation limiting the extent of extrapolation is the similarity of the 2600 ft data to the background data taken at the old Hanford Townsite and at the 300 Area, with regard both to spectral distribution and

DECLASSIFIED

-24-

BNWL

to magnitude. The low energy component of background appears to be a major fraction of the total observed at 2600 ft from B Reactor, and even the high energy background component (around 6 MeV) appears to be approximately half of the total at the 2600 ft point. Assuming a factor of 10 absorption of 6 MeV gamma in one-half mile of air and a further reduction due to inverse square losses, sensitivity of the collimating assembly at one mile for reactor-associated 6 MeV gamma activity would be expected to be about 2% of the 6 MeV background reading at that point.

A highly penetrating component of the gamma spectrum is available in the Hanford reactor effluent. Even so, it is concluded that perimeter observations of gamma activity from Hanford reactors could be considered as evidence of reactor operation or nonoperation, but not as conclusive verification. Application of the Hanford gamma results for other types of reactors and other concepts of detection is considered in Section III, Discussion.

B. Infrared Measurements

The tremendous amount of heat produced by nuclear reactors is directly related in the case of production reactors to their rate of production of plutonium or other isotopes. Presumably the host nation to a shutdown agreement would not permit direct measurement of coolant flow and temperature rise. The heat has to be dissipated, however, and should evidence itself as higher temperatures in some way--in the reactor building, in effluent lines, in heat exchangers, in storage basins, or in the ultimate heat sink itself, whether it be a body of water or the atmosphere.

All bodies above zero degrees absolute temperature emit infrared radiation. The amount emitted and detected depends on many factors--emissivity of the radiator, the influence of atmospheric absorption, and the characteristics of the radiometer used. The temperature of the body itself further depends on the source of its heat and on the conductivity and conduction paths of adjacent materials and components. In addition to the primary sources, extraneous influences such as sunlight and shadow, wall thickness variations, internal air conditioning, and outside weather effects make the calculation of expected surface temperatures extremely complicated and

DECLASSIFIED
-25-

BNV **CC-457**

unreliable. It was concluded that actual infrared measurements would have to be made in order to determine the effectiveness of this method for perimeter determination of reactor operation. The equipment used would have to permit the attainment of high accuracy of individual temperature determinations and comparisons over relatively small increments of distance. On the other hand, fast response and readout would not be essential for purposes of ground detection, as temperature indications sought as evidence would not be expected to fluctuate rapidly.

This section presents the results of the field measurements carried out with infrared radiometer equipment made available for this purpose. It was possible to find civilian equipment having the required sensitivity characteristics. The equipment was sufficiently expensive, however, that it was necessary to negotiate its use on a rental basis for this program.

1. Equipment

A specially assembled Barnes model R-8T1 radiometer having a portable power supply was used in the experiments. Figure 5 shows the equipment as it was set up in the field. A filter passing only those infrared wavelengths between 8 and 13 μ was used in the instrument, since this region constitutes one of the major atmospheric "windows" (low atmospheric absorption and emissivity). Although noise due to atmospheric turbulence and other effects was expected to be greater than 1 $^{\circ}\text{C}$, an instrument having a noise equivalent temperature of 0.05 $^{\circ}\text{C}$ was selected to permit detailed close-up measurements of small temperature differences where required. The noise-equivalent power density for the instrument was $5.51 \times 10^{-2} \text{ W/cm}^2$. A total system time constant of 1 sec was selected as being a reasonable compromise between rapidity of measurement and the signal-to-noise ratio (which is improved as the time constant is increased). Field of view of the radiometer was restricted to 0.001 radian to permit resolution of the "downcomer" regions on the reactors from a distance of 1 mile. (The "downcomer" is essentially a large standpipe accepting the entire reactor effluent coolant and routing it to underground piping.) The detector used in the radiometer was a germanium immersed thermistor bolometer type.

DECLASSIFIED

-26-

BNW

FIGURE 5

Infrared Radiometer in Field Use

The effective target radiance for a black body target is given by

$$\bar{N}_T = \int_8^{13} R_r(\lambda) N_{BB}(\lambda, T) d\lambda, \quad (1)$$

where λ is the wavelength, T the absolute temperature, R_r the relative responsivity (normalized to the peak response) of the detection system and filter, and N_{BB} is the actual radiance of the black body target. Since R_r is not usually a simple function of wavelength, numerical integration is necessary. A table and curves of $\bar{N}_T$ values versus target temperature obtained in this way were furnished by the radiometer manufacturer. The

DECLASSIFIED

-27-

BN

N_T values, under the conditions of experiments described below, are related to various read-outs on the instrument by

$$\bar{N}_T = \bar{N}_R + \frac{1}{K_S} \left(\frac{S}{G} V_{out} - V_{ETO} \right), \quad (2)$$

where $\bar{N}_R$ is the effective radiance of the internal blackbody reference in the instrument, K_S is the system response factor, G is the amplifier gain, S is the attenuator setting, V_{out} is the output voltage as read from the instrument output meter, and V_{ETO} is the electronic offset voltage injected at the amplifier input. Values of K_S and G were 9.0×10^{-2} V/W/cm² - steradian and 1.03×10^6 , respectively. Values of S used during the experiments ranged from 1 (0 dB) to 129.5 (42 dB), values of V_{ETO} ranged from 0 to 125 microvolts, as read directly in microvolts from the ETO dial setting. The value of $\bar{N}_R$ ranged from 2.71×10^{-3} to 3.72×10^{-3} W/cm² steradian depending on the environmental temperature; the value generally applicable in the test conditions encountered was 3.55×10^{-3} . The internal blackbody reference had no provision for cooling, so it was always necessary to set the control temperature to a point above the environmental temperature. The radiometer manufacturer furnished a set of curves relating the black body controller setting to the equivalent sample temperature required to produce the same infrared flux at the detector as that produced at the detector by the black body. The equivalent sample temperature was then applied to the $\bar{N}_T$ versus T curves to determine the effective value of $\bar{N}_R$. The controller setting for the internal reference black body was left constant to the extent that variations in environmental temperature would allow. A simpler procedure would be simply to turn off the controller and let the internal black body temperature come to equilibrium with the internal instrument temperature. This temperature could then be read directly from a meter on the instrument. However, this procedure was not used since the environmental temperature, and hence the instrument temperature, was found to change rather quickly on occasion. This would have possibly caused error in the black body temperature measurement since the internal instrument temperature sensor is not located within the black body.

Emissivity of the target is also important in computing temperatures corresponding to measured target radiances. Since differences in temperature, rather than absolute temperature values, were of most interest in the present study, and since measurement of emissivities of each target would have required a more extensive program, all targets (concrete, earth, and paint) were assumed to be gray bodies having an effective emissivity of 0.9, independent of wavelength and temperature. Hence, the value of $\bar{N}_T$ computed from radiometer read-outs using Equation (2) must be divided by 0.9 to obtain the value of $\bar{N}_T$ that would have been detected had the target been a black body. The adjusted $\bar{N}_T$ value can then be used with the curves corresponding to Equation (1) to determine actual target temperatures. A sample computation in tabular form is shown in Table III.

TABLE III
EXAMPLE READOUT AND CALCULATIONAL DATA USED TO
DETERMINE TARGET TEMPERATURES

Day-Time	Point	V _{out}	BB Dial	S	ETO Dial	$\frac{S}{K_S G}$ V _{out}	$\frac{V_{ETO}}{K_S}$	$\bar{N}_R$	$\bar{N}_T$	$\bar{N}_{T/0.9}$	T °C
7-1010 hr	0*	+5.0	950	1	80	5.4×10^{-5}	0.89×10^{-3}	3.55×10^{-3}	2.71×10^{-3}	3.01×10^{-3}	11.7
7-1010 hr	50*	-4.0	950	1	80	-4.3×10^{-5}	0.89×10^{-3}	3.55×10^{-3}	2.62×10^{-3}	2.91×10^{-3}	9.9
7-0955 hr	A**	+4.0	950	125.9	80	5.45×10^{-3}	0.89×10^{-3}	3.55×10^{-3}	8.11×10^{-3}	9.02×10^{-3}	91.3

*Ground surface temperature measurement over K-EAST effluent line

**K-EAST effluent basin

2. Heat Flow Theory

Although exterior surface temperatures are a function of many variables, a rough estimate of the time required for an internal temperature change to influence exterior surface temperatures can be obtained by considering some highly idealized cases. Simplifying assumptions made in preliminary calculations were that the exterior surfaces are perfectly insulated, that the heat source is in perfect contact with the interior, and that the heat source temperature is initially the same as ambient and then increases to the effluent temperature at time $t = 0$. The influence of a

DECLASSIFIED

75 °C increase in effluent temperature on the exterior surface temperatures of the 5 ft thick concrete wall surrounding the "downcomer" and of the earth fill covering an effluent pipe are considered in this discussion as examples. Initial temperatures within the wall or earth fill are considered to be uniform and equal to ambient.

Initially, to get the "downcomer" wall-heating problem into a form which can be solved by adapting a previous solution, we shall consider only changes in temperatures. Hence, the solution becomes independent of the initial uniform temperature (assuming constant thermal properties) and it can be chosen at any level desired. The initial temperature can thus be chosen at negative the effluent temperature so that the effluent temperature becomes zero upon increasing. Under these conditions, a solution given by Jakob⁽¹⁾ can be adapted. The solution for the difference between the outside wall temperature and effluent temperature is thus obtained as

$$\left| \Delta T_W \right| = \left| \frac{\Delta T_O}{S} \sum_{v=1}^{\infty} \frac{2S}{v\pi} \left[1 - \cos v\pi \right] \left[\exp - \left(\frac{v^2 \pi^2 \alpha t}{4S^2} \right) \right] \sin \frac{v\pi}{2} \right| \quad (3)$$

where ΔT_O is the amount by which the effluent temperature exceeds the initial temperature at time $t > 0$, S is the wall thickness, α is the thermal diffusivity, and t is time. The actual value of exterior surface temperature can then be obtained as

$$T = T_E - \left| \Delta T_W \right| \quad (4)$$

where T_E is the effluent temperature at time $t > 0$.

A study of the plot of T versus t is informative in estimating the time required for the temperature change to be noticeable on the outer surface of the 5 ft thick wall around the downcomer. Figure 6 shows values of outer wall surface temperature computed as a function of time after startup for an initial temperature of 25 °C, and a sudden increase of the inner surface

(1) Jakob, Max, Heat Transfer, vol. 1, p. 258, Wiley & Sons. 1949.

DECLASSIFIED

-30-

BNW

FIGURE 6

Calculated Temperature on Outer Surface of Downcomer Wall
Versus Time After Startup

temperature to 100°C at startup. Also shown are the temperatures on the outside of a 5 ft thick wall having a 25°C sudden increase in inner surface temperature which was initially at 25°C . This temperature increase might be expected in the effluent face area of a reactor upon startup. It must be emphasized that these temperatures were obtained for the simplified case where the external surfaces are considered insulated and the internal surfaces coupled as stated above. The actual surface temperatures would be very difficult to calculate theoretically because of the large number of other variables which change in an unpredictable manner. Examples of these are external wind and convection currents, sunlight and cloud cover (on sunny side), ambient air temperature, contact conductance between the effluent line and wall, and warm drafts from building vents. Comparison of identical walls subjected to identical variables,

DECLASSIFIED-1-

BM

except for internal heating due to reactor operation, might be used to determine whether the reactor was operating provided certain conditions are met. These will be discussed later under the conclusions.

Solution for the surface temperature of the earth over the effluent pipe can be obtained by applying the method of images to a solution given by Carslaw and Jaeger.⁽¹⁾ The solution thus obtained, considering initial temperatures at zero, is

$$T = 2T_E + \frac{4T_E}{\pi} \int_0^{\infty} e^{-\alpha u^2 t} \frac{J_0(ur) \gamma_0(ua) - \gamma_0(ur) J_0(ua)}{J_0^2(au) + \gamma_0^2(au)} \frac{du}{u} \quad (5)$$

where T is the temperature at the radius r from the center of the pipe, T_E is the constant temperature reached by the pipe at $t > 0$, t is time, α is thermal diffusivity of earth around the pipe, and a is the radius of the pipe. Note that for points on the surface of the earth, $r = (d^2 + x^2)^{\frac{1}{2}}$, where d is the depth of the center of the pipe below the surface of the earth, and x is the distance along the surface of the earth from a point directly over the pipe to the point located at r . Table IV gives the temperatures on the surface, assuming $\alpha = 0.002 \text{ cm}^2/\text{sec}$, the initial temperature to be 0°C at time $t = 0$, $d = 15 \text{ ft}$, and $a = 30 \text{ in}$.

TABLE IV
CALCULATED GROUND SURFACE TEMPERATURE RISES
VERSUS TIME AND HEATED PIPE DEPTH

$x \text{ (ft)}$	$t \text{ (days)}$				
	<u>14</u>	<u>30</u>	<u>42</u>	<u>60</u>	<u>84</u>
0	0.0	0.0	0.0	0.8	2.2 °C
8	0.0	0.0	0.0	0.2	0.6
16	0.0	0.0	0.0	0.0	0.0

(1) Carslaw, H. S. and J. C. Jaeger, Conduction of Heat in Solids, p. 335, 2nd ed., Oxford, 1959.

DECLASSIFIED

BNW

Here, as in the case of the wall temperature calculations, the surface temperature is influenced by many variables, and the absolute surface temperature is only approximate. However, in this case the ground a short distance away from the effluent line might be used as a standard for comparison, since it is subjected to approximately the same external variables as the ground directly over the effluent line. In this case, however, variations in emissivity from one point to another could cause differences in heating from sunlight. This difficulty was pronounced in some regions as discussed below in the section on experimental results. Hence, such measurements would have to be made in early morning prior to sunrise, preferably after several days of overcast weather.

3. Experimental Measurements

Measurements were all made over a period of 13 consecutive days. The actual dates are not given because of their security relationship to production time; the numbers of days given in the data below are the number of days elapsed after the first measurements were made. All presentations of the data below have been converted to temperatures and are shown graphically. Each presentation is discussed under the heading of the appropriate figure number or numbers.

Figure 7 - KE Reactor. Based on Figure 6, one would expect a difference in temperature between Point A (external temperature of wall adjacent to downcomer) and Point D (external temperature of the wall behind the discharge area) in Figure 7. (See Figure 14, p. 42, for relative location of Points A and D. Point A' was on the rear wall of the K Reactor adjacent to the downcomers, and at approximately the same elevation as Point A; because of secondary walls to the rear of the D downcomer, there was not an equivalent data point available at D and DR). Unfortunately, the difference in temperature of these two points shows no correlation with operation of the reactor. Several possible reasons for this are that, 1) the sun shines on Point A during part of the day, whereas it does not shine on Point D; 2) the "downcomer" is not very closely coupled thermally to the interior of the wall at Point A; and 3) wind does not generally blow equally at these two points. Corresponding readings were taken at corresponding

DECLASSIFIED

-33-

BN

times to the extent feasible. Sunlight conditions would not affect Points A' and D directly at the K's, however, since the discharge face is at the north of the K Reactors.

FIGURE 7

K-East Outer Wall Surface Temperatures. Point A: 5' Thick Concrete Wall Adjacent to Downcomer. Point D: 5' Thick Concrete Wall Behind Rear Discharge Area at Point far Away from Downcomer. Distance from Radiometer to Point A was 0.6 Mile, and to Point D was 0.1 Mile.

DECLASSIFIED

BN

Figure 8 - KE Reactor. The wall at Point A' is even more loosely coupled thermally to the downcomer than at Point A, but it is subjected to approximately the same external variables as Point D, and is closer to the downcomer than D. For this reason, Point A' might be expected to be at about the same temperature as D during shutdown and at a higher temperature during operation. The plots in Figure 8 do not show such a definite correlation with reactor status. Reasons for the lack of correlation are open to conjecture.

FIGURE 8

K-East Outer Wall Surface Temperatures. Point A': 5' Thick Wall Behind Discharge Area near Downcomer. Point D: 5' Thick Concrete Wall Behind Discharge Area at Point far from Downcomer. Distance from Both Points to Radiometer was Approximately 0.1 Mile*.

DECLASSIFIED

-35-

BN

Figure 9 - KE and KW. Figure 9 shows Point A on both the K-East Reactor and the K-West Reactor. Since these two reactors are identical and face identical directions, Point A on the two reactors is subjected to most of the same variables. Some small differences in air currents, cloud cover, etc., might be expected due to the approximately 0.2 mile separation of the two buildings. Based on calculations shown by Figure 6, temperature changes of a degree or so might be expected at one reactor relative to the other at Point A within four or five days or so after one reactor was shutdown and the other had started up. This was not the case as seen in Figure 9. Point A on K-East ran cooler than K-West until the last day of the measurements, even though each reactor had been shutdown and started up for three days each at different times. In addition, the temperature difference between the two reactors on day five was less than on day zero, rather than greater as would be expected on the basis of the theoretical calculations. The reason for this discrepancy could be that the coupling between the down-comer and outer wall is loose rather than close.

Figures 10 and 11. Surface Temperatures Along KE Effluent Line. These figures show bare ground surface temperature measured at various distances from the buried effluent lines approximately 75 yards from the reactor at two locations on two different days. The ground temperatures were obtained with the radiometer viewing nearly vertically downward from its stand on the pickup truck. It was noted during initial attempts at making these measurements that sunlight caused random ground surface temperature differences even greater than those associated with the effluent lines. Variations in emissivity of stones, etc. on the surface were at least partially responsible. Temperatures obtained with thermometers imbedded in sand would probably have given equivalent accuracy. The measurements shown in Figures 10 and 11 were made on overcast days. Correlation of difference between ground surface temperatures at 0 and 50 ft with reactor operation is evident.

DECLASSIFIED

BN

FIGURE 9

K-East and K-West - Outer Surface Temperature of 5' Thick Concrete Wall Adjacent to Downcomer. Distance*: K-East to Radiometer = 0.2 Mile; K-West to Radiometer = 0.6 Mile.

DECLASSIFIED

-37-

BNV

FIGURE 10

Ground Surface Temperature vs. Distance Measured Along a line
Perpendicular to the Direction of the K-East Effluent Line at two
Different Locations on Measurement Day No. 7.

DECLASSIFIED

-38-

BNV L-GE

FIGURE 11

Ground Surface Temperature vs. Distance Measured Along a line Perpendicular to the Direction of the K-East Effluent line at two Different Locations on the Measurement Day No. 8.

Figure 12 - KE and KW Retention Basins. This figure shows a strong correlation of basin surface temperature with operating status of the reactor. Although these measurements were made at 300 ft to allow precise comparisons, it should be straightforward to make them from a distance of one mile or more.

DECLASSIFIED

-39-

BNV

FIGURE 12

K-East and K-West - Retention Basin Outer Surface Temperatures.
Distance from Radiometer to each Basin was Approximately 300'.

DECLASSIFIED

-40-

BNV

Figure 13—Radiometer Viewing D Reactor. This photograph with the radiometer focused on the D Reactor shows the typical condensate cloud on a cool day. Such clouds are visibly evident even on summer mornings with basin temperatures in the range of 90 °C. Outside temperatures during most of the infrared field measurements were near the freezing level. At the time this photograph was taken temperatures were slightly below freezing, the sky was clear, and there was a brisk north breeze.

FIGURE 13

Figure 14—"Near" Side and Rear Views of D Reactor. Two views of the D Reactor are shown in these photographs. The first shows the "near" side of the reactor through which the control rods enter; the

DECLASSIFIED

-41-

B

downcomer is enclosed in the solid concrete structure rising at the left of the picture. The second photo shows the rear secondary shielding wall. At the bottom of the rear face picture is the transfer area for discharged metal, at the left and right are housings for the rear risers, at the far right is the downcomer, and at the top is the area enclosing the vertical safety rods.

The rear face photo especially illustrates the problem created by shadows.

Figure 15-D and DR Reactors. This figure shows temperature measurements made from a distance of approximately one mile on the surface of the 5 ft thick concrete wall adjacent to the downcomer of the D and DR Reactors. At the time these measurements were made, D Reactor was operating, and DR had been shut down for nearly a year. Rooms in the operating D Reactor building were being heated with added nonreactor heat, whereas most rooms in the shutdown DR building were not. Areas of "downcomer" wall in which the temperatures were measured on the two reactors are comparable insofar as thickness and orientation is concerned. Hence, the two areas were subjected to comparable influences from external variables. Note the striking demonstration of the lack of correlation of absolute external temperature with the operating status of the reactor; the eighth day temperature of the long shutdown DR Reactor was actually higher than the 11th and 12th day temperatures of the operating D Reactor. However, there is a striking correlation of the difference in temperature of the comparable "downcomer" walls with relative operating status of the two reactors.

As indicated by the solid and broken lines in Figure 15, measurements were made from two different locations on the 11th and 12th days. No measurement could be made on D Reactor from the point near the basin on the 12th day due to steam from the basin in the line of sight (as shown by Figure 13 photograph).

DECLASSIFIED

-42

BNW

FIGURE 14

"Nearside" and Rear Views - D Reactor

DECLASSIFIED

-43-

BN

FIGURE 15

D and DR[†] - Outer Surface Temperature of 5' Thick Concrete Wall Adjacent to Downcomer, Distance Approximately 1 Mile. Temperature Points with Broken Lines were Measured from North-East Corner of Perimeter Fence. Points with Solid Lines Indicate Measurements from Perimeter Near DR Basin.

Figure 16-D and DR. The main purpose of the data shown in Figure 16 is to provide a comparison of data taken at approximately 300 ft with that taken at approximately one mile as presented in Figure 15. It was not possible to take the data from the two distances at the same time. However, changes in environmental conditions were minimal during the time required to move the equipment from one location to the other. The data in Figure 16 were within ± 0.8 °C of corresponding data in Figure 15 on the eighth day. On the 12th day, however, temperatures in Figure 16

DECLASSIFIED

-44-

BN

were 2.5 to 3 °C higher than those in Figure 15. This difference was possibly due to the greater atmospheric absorption of the infrared on the 12th day than on the 8th. It might also be due to the nonuniformity of temperature on the source, and the reduction in size of the viewed area as the radiometer is moved closer in case of irregular temperature gradients across the area. (The viewed area would be approximately 5 x 5 ft at one mile from the target, but only about 0.28 x 0.28 ft at 300 ft.)

FIGURE 16

D and DR† - Outer Surface Temperature of 5 ft Thick Concrete Wall Adjacent to Downcomer. Measurements Made from a Distance of Approximately 300 ft.

Figure 17-Rear Wall Temperatures, D and DR. This figure shows the temperatures on the rear walls of the D and DR Reactors. These walls are 5 ft thick. The regions in which the temperatures were measured were near the top of the discharge area in each case.

Also shown in the figure are the temperatures near the tops of the exhaust stacks for the two reactors. These temperatures are probably more strongly related to whether or not the building is heated than to the operating status of the reactor.

It is interesting to note that the rear wall temperatures shown in Figure 17 are higher than the downcomer wall temperatures shown in Figure 15, even though the wall thicknesses were comparable and the downcomer at the D Reactor is hotter than the discharge area. This is believed due to intense sunlight which was incident on the rear wall, but not on the measurement side of the downcomer at the time the measurements were made.

FIGURE 17

D and DR† Rear Outer Wall Surface and Stack Temperature Measured from North-East Corner at Distance of Approximately 1 Mile

Figure 18—Rear Wall Traverses, D and DR. Data in Figure 18 indicate the temperatures at different locations along a line from the bottom of the rear face to the top. The difference in contour of the temperature on the two days shown may be due to a difference in shadows. The

DECLASSIFIED

-46-

BNV [REDACTED]

eight day measurements were made in the afternoon, whereas the 12th day measurements were made in the morning. In addition, shadows cast on the rear faces of the buildings are somewhat different from those cast on the DR Building.

†NOTE: D Operating
DR Shut-Down

*NOTE: Strong Sunlight on Parts of Top of Rear Face
at DR. Bottom in Deep Shade

FIGURE 18

D and DR† Rear Outer Wall Surface Temperature vs. Distance up Wall from Bottom. Distance from Wall to Radiometer was Approximately 300 ft

DECLASSIFIED

-47-

BNW

Figure 19— Ground Temperatures Over D Effluent Line. Several unsuccessful attempts were made prior to obtaining the ground surface temperature data shown in this figure. It was necessary to make the measurements early in the morning before heat from the sun was appreciable. Later in the day temperature variations at random locations were larger than those resulting from the 5 ft diameter effluent line the top of which is approximately 8 ft below the ground surface. In some locations, differences in emissivity were believed to cause temperature differences subsequent to heating from sunlight. Temperature measurements were made in the same manner as at the K Reactor effluent line locations, from nearly overhead with the infrared radiometer.

In one location, approximately 80 yd from the reactor building, the effluent line passes under an asphalt roadway. The surface emissivity of the roadway should be high and relatively uniform. However, it was observed that heat from the sun caused random hot spots on the roadway in locations other than those over the effluent line. These may have resulted from differences in thickness of the roadway, or differences in thermal properties of the roadway or the earth under the roadway. The radiometer signal differences were due to actual temperature differences, rather than differences in reflection of infrared from the sun. To test this conclusion, a shadow was cast on the area viewed by the radiometer. A slow decrease in signal followed. When the shadow was removed, a slow increase in signal resulted. Had the signal change been due to reflected energy, the signal increase or decrease would have been immediate.

River Temperature Measurements. An attempt was made to measure river temperatures upstream and downstream from the reactors. It was not possible to make the measurements from a point sufficiently high to avoid reflections due to the large angle of incidence (as measured with respect to normal to the water surface). The ratio of direct radiation seen by an observer would be directly proportional to the cosine of the observer angle from the normal; conversely, the reflection would increase with angle from the normal. Intense reflection of surroundings was observed. In fact, at

DECLASSIFIED

-48-

BNW

FIGURE 19

Ground Surface Temperature vs. Distance Measured Along a Line
Perpendicular to Direction of D Effluent Line

one point, estimated to be slightly over a half mile from the observer whose elevation was on the order of 50 ft above the river surface, an increase in radiometer signal corresponded in location to the visible reflection of a pole. The pole was warmer than the other surroundings as confirmed by direct infrared measurement. A high infrared signal from the surface of the water was noted in the highly localized region of the visible reflection of the pole. Infrared measurements of river temperature should be made as nearly normal to the river surface as possible, preferably at night.

III. Discussion

Results of field testing of infrared and gamma spectroscopy observations reported in the preceding section are directly applicable only to the

DECLASSIFIED

-49-

[REDACTED] B [REDACTED]

Hanford production reactors under the conditions existing at the time. The primary purpose of the measurements was, of course, to determine the applicability of perimeter inspection to other reactor types and environs as well, and the feasibility of perimeter inspection in the face of counter-measures. Care is required, however, in extrapolating these data to foreign situations. Although the number of neutrons, gamma photons, and thermal units of heat generated are directly proportional to the plutonium production (or equivalent) of a particular reactor, differences in building design can change outside indications significantly. For example, another foot of concrete will reduce gamma and neutron radiation by a factor of 10. This section is addressed to consideration of reactor types in general and to relating field observations to the ground rules listed in the Appendix.

A. Applicability to Other Reactor Designs and Environs

1. Nuclear Radiation

The gamma spectrum and neutron data obtained were not sufficient for disclosing operation or nonoperation of a Hanford reactor from a perimeter distance of a mile. The indications that the primary source of observed gamma activity emanated from the retention basin casts doubt on the value of gamma spectrum data for perimeter inspection at closer distances where nearby reactors, not covered by the shutdown agreement could use common or adjacent effluent basins.

Closed loop systems would not have the problem of reactor effluent activity dispersing in the surrounding environs. Except for nonroutine events such as fuel element ruptures or system leaks, high purity recirculating coolant systems would be expected to have relatively low gamma activity aside from that due to N^{16} in water; it would be expected that shielding provided by the building design around any closed loop would be at least comparable in effectiveness to that provided by the rear secondary shield in the case of the one-pass system of the Hanford production reactors.

Trace amounts of radioactivity may be found around the environs of any reactor. Activation products expected from different types of reactor coolant, moderator, fuel, and ventilation systems could include one or more of the following: N^{16} , P^{32} , C^{14} , Ar^{41} , tritium, and any of numerous fission [REDACTED]

DECLASSIFIED

-50-

BN

products such as Cs^{137} and Cs^{138} . Samples from the air, water, or grounds about the perimeter could be analyzed by anti-coincidence counting techniques in the laboratory and compared to activity of samples taken in an area known to be remote from the reactors. There is a good possibility that data obtained in this manner would reveal a single reactor's operation if it were occurring, but it is very doubtful that it could be used to indicate which reactor(s) out of a local complex of reactors contributed to the activity or at what level it contributed.

The utilization of a large scintillation crystal detector, a spectrum analyzer, and a highly directional collimator provided gamma measurements of sufficient sensitivity to establish that this method had possibilities for observing direct reactor radiation at perimeter distances up to a mile, but not conclusive evidence unless system sensitivity was greatly improved or unless shielding of some part of the reactor or its coolant system were inadvertently underdesigned. Several possibilities for improving the gamma detection system are discussed below which should be investigated if the perimeter monitoring system is to be adopted.

One obvious possibility is to increase the collimator shielding (assuming for the moment that the $\frac{3}{4}$ ton of lead used in the experimental system could be increased). However, limitations on the amount of background reduction attainable by use of additional lead shielding are suggested in the literature⁽¹⁾ from studies which indicate neutron emission from meson interactions with the shielding materials. Capture of a moderated neutron in the sodium or thallium of the NaI(Tl) crystal would cause emission of a 6 MeV gamma photon, and evidence of a peak in this region has been observed as lead shielding is added around a large NaI(Tl) crystal. Although low energy gamma activity is cut down appreciably as shielding is added, the high energy component appears to reach a minimum value which is within a third to half that of the unshielded value. The gamma radiation of ~6 MeV could emanate from the capture of a moderated neutron by sodium or thallium, by mesonic lead X-rays caused by interaction of mesons with the lead

(1) ANL-6646, "Neutron Production in Massive Shields, and Effect Upon the Low-Energy Gamma-Ray Background," H. A. May, Radiation Physics Annual Report, January - June, 1962.

DECLASSIFIED

-51-

BNW

shielding, either to produce neutrons for moderation and capture or to produce the mesonic lead X-ray. The effect of a level-out in high energy gammas was not noted, however, as lead shielding was added around a plastic phosphor. Thus the use of iron shielding and/or plastic phosphor should attenuate the 6 MeV gamma background. ⁽¹⁾

Another possibility for improving the directional sensitivity is that of using large double crystals with anti-coincidence circuitry, the "gamma telescope" concept. Vendor sheets of the Harshaw Chemical Company mention that they can fulfill requests for special sizes and geometries to fit customer demands. Because of their high cost and mechanical properties, owners of such crystals appear highly reluctant to loan them, especially for field work without controlled temperature conditions. Discussions with vendor technical personnel indicated that an optimum of detector sensitivity could probably be approached with a single elongated crystal, for example 5 in. long by 3 in. diameter, shielded with iron. It appeared from these discussions that vendor counting rates in the 3 to 4 MeV range with 6 in. of iron around the crystal were of the same order of magnitude as those at Hanford with 2 in. of lead around the crystal.

Should anti-coincidence shielding be attempted plastic phosphors should be considered for use as an outer shield. The plastic phosphor is cheaper than the NaI(Tl) and as mentioned previously does not appear to have the comparable disadvantage of n- γ reactions. Also it would provide protection to the more fragile NaI(Tl) crystal against temperature variations. The cost of a 3 x 5 in. NaI(Tl) crystal with full length magnetic shielding is of the order of \$1200 exclusive of electronics components.

It is thus concluded that neutron detection should not be considered as a primary perimeter technique for determining reactor operation, and gamma detection should be considered as a primary method only to the extent that:

- Equipment having laboratory order of sophistication were to be utilized.

(1) Personal Communication, C. W. Thomas, Radiological Chemistry, Battelle-Northwest. December 30, 1965.

DECLASSIFIED

-52-

37

- The equipment were manned by professionally trained scientific personnel.
- Comprehensive field tests with such equipment at the sites of the types of reactors to be monitored were to demonstrate that sufficient signal characteristic of reactor operation could be discriminated in the face of known and surreptitious backgrounds to give undisputed evidence of violation.
- Funding would permit the procurement, care, and transport of highly sophisticated equipment, and time would not limit statistical criteria in the obtaining of long-term background, trend, and difference data.

2. Infrared Radiation

As pointed out in the experimental section, sensitivity of temperature detection by a good infrared radiometer is not reduced so drastically by distance as in the case of nuclear radiation. Although uncertainties are introduced in temperature determinations by effects such as rain and snow, emissivity constants, reflections, and size of field of view, there still exists reasonable capability for assessment of temperatures of viewed objects and differences in temperatures between viewed objects at perimeter distances. The latter statement should be qualified to mean objects viewed from a near normal position. It would be wrong to imply, for instance, that comparisons would be legitimate where a very low angle of observation was utilized as in the case of ground and river data taken by an observer some distance away standing at surface level.

The problem, however, is to determine that temperatures shown by infrared observations are characteristic of reactor operation and, hopefully, that they indicate the production level if the reactor is operating. (No consideration is made at this point in the discussion of potential counter-measures). Infrared experimental data given earlier in this report indicated that the retention basin was the only object which yielded reasonably conclusive results. Building temperatures were strongly affected by outside weather and inside ventilation. Unless a known identical base case [REDACTED] was available for immediate comparisons, as in the case of D and [REDACTED]

DECLASSIFIED

-53-

37

DR in the experimental measurements, the absolute temperatures obtained would be of only indirect circumstantial value. Conflicting KE and KW data would indicate that it could not be conclusively shown whether or not one of them were shut down, especially if they were air conditioned; this latter possibility would be allowable under the given ground-rules permitting use of the building for other purposes.

Although outside weather conditions are bothersome in causing changes in building surface temperatures, colder weather is generally more favorable for disclosing the effects of wall thickness, and gradients in building temperatures accompanying effects of air conditioning within the building. On a cold day, a thin outer wall with a 25 °C interior surface temperature would have a much higher external temperature than would a 5 foot thick wall (of the same material) with a 100 °C interior surface temperature. Observations of outer wall temperatures would be expected to be most indicative of high temperature internal heat sources and least biased by effects of building air conditioning on overcast days when the outside temperature was close to room temperatures within the building.

Reasonably good results for observation of temperature gradients on each side of underground effluent lines were obtained at the K Reactor. Experience at the D Area showed, however, that if such measurements were to be reliable they had to be made in the early morning or under persisting cloudiness. Rain or snow would reduce the reliability of the readings temporarily; however, it has been observed in the case of heavy snowfall and subsequent melting that the presence of underground effluent lines is revealed where they run under roadways and even along their entire route shortly before all the snow has melted.

Except where underground effluent lines are known to exist outside or close to the perimeter, however, the low angle of observation would reduce considerably the reliability of temperature traverses taken from the perimeter. As indicated by theoretical calculations and by observations, the differences noted under the best conditions, taken nearly normal to the ground, are of the order of only 1 to 2 °C.

DECLASSIFIED

-54-

BI [REDACTED]

[REDACTED]

The high temperatures noted in the effluent retention basins strongly indicate reactor operation. The power required to heat the water to a given temperature is essentially proportional to the flow, however. A doubling of flow with the reactor held at constant level would indicate to the observer a power level of only half that originally. At the other extreme, a retention basin used for evaporative cooling only--that is, with no exit flow to the river--could be held at near boiling temperatures with very little waste heat from some industrial process going on within the shutdown area. Should the latter condition exist, as it legitimately could under the ground rules, the infrared data from the basin could lead the observer to conclude falsely that the reactor was operating at a high production rate.

As discussed in the case of nuclear radiation, the effectiveness of infrared monitoring will vary with different reactor types, and the most sensitive point for revealing maximum temperature will be different. For example, the outlet stack of a one-pass air-cooled reactor would correspond in temperature sensitivity to the retention basin of a one-pass water-cooled reactor. The primary loop of closed-loop systems generally run at higher temperatures than do single-pass systems. Insulation and ventilation required for avoidance of excessive building temperatures and thermal gradients would be expected to keep outside building temperatures of recirculating reactors at about the same level as those for one-pass reactors. Infrared radiometer observations made on operating and shutdown Hanford production reactors are thus considered to be reasonably representative of infrared potentials and drawbacks for monitoring other reactor types.

3. Potential Countermeasures

A large variety of countermeasures can be conceived against detection of operation by either nuclear radiation or by temperatures. The principal is simple in either case--to reduce the signal-to-noise ratio--either by increasing the background or by shielding out the signal. In the case of excessive radiation sources such as beam ports or other perforations of the shield, reductions to near background levels may usually be made relatively simply by addition of shadow shields, step plugs, or shimming. Should

[REDACTED] [REDACTED]

DECLASSIFIED

-55-

BNWL-CC-437

gamma radiation signals from the reactor still be higher than observed in the Hanford field tests, the countermeasure likely to be most effective is the deliberate use of weak radiation sources around the area to increase the background level. Variations in concentrations of sources could be made from time to time to prevent disclosure of half-lives and thus of the deliberate nature of the countermeasure.

Temperatures observed from buildings and underground lines indicate that rather minor modifications inside the reactor building, such as addition of heat baffles, coolant pipes in contact with building walls, and changes in air conditioning practices would further reduce the effectiveness of infrared monitoring of reactor building walls.

Countermeasures against detection of ground temperatures around underground effluent coolant pipes would probably not be considered necessary to prevent disclosure of a violation. The obvious countermeasure in this case is to reroute, insulate, and/or lower the depth of the effluent pipes.

The relocation of the principal heat sink would very likely be considered necessary by a nation attempting to violate the agreement. In this case effluent lines would definitely have to be buried deeply and measures taken to prevent their detection by sonic or other means. Use of common piping, pumping, and effluent facilities from other areas in the reactor complex still operating legitimately would prevent inflow and outflow patterns from being identified with the "shutdown" reactor.

4. "Black Box" Detection

The use of "black boxes" containing known sealed instrumentation to detect reactor operation could give some advantage in permitting use of more sophisticated instrumentation. Nuclear and infrared detection by such a device would be subject to the same types of countermeasures described above. The freedom of motion available to a field observer with portable instruments may give much better assurance of violation detection than would "black box" observation from a single point. Use of other signals by the "black box" to disclose activity within the area--such as trucks, power line transmission,

DECLASSIFIED

-56-

BNV

people, and machinery--would be indirect indications of activity not necessarily in violation of the ground rules given for the study. In order to have the black box concept considered feasible for field use, an expenditure of time and money at least one and probably two orders of magnitude greater than carried out in this study would appear necessary.

B. Consideration of Alternate Criteria

The Ground Rules provided for the study program are listed in the order given in the Appendix of this report. Conclusions resulting from field work carried out in this study are that industrial activities within an enclosed area could be detected from a one-mile perimeter with reasonable certainty, but discrimination between nuclear activity and other industrial activity under the given ground rules could not be assured with perimeter inspection. The point at which other activity would inhibit an inspection system is simply when occupancy and heating of the reactor building and/or supporting facilities occurs. If the observer were permitted to enter the area and the reactor building whenever perimeter observations indicated building activity, he could see whether the nature of activity indicated an acceptable production process or whether alterations suggestive of countermeasures had been made in shields, walls, and piping subsequent to the initial reactor walkthrough. The two ground rules most disadvantageous from the standpoint of assured disclosure of reactor operation from the area perimeter are:

- Permission of alternate activity by the host nation within the area.
- The potential use by nearby reactors of common support facilities and heat sinks.

Regardless of the sophistication of perimeter detection methods, the feasibility of the inspection system must be judged on the basis that it provides circumstantial rather than incontrovertible evidence.

Alternate I, 24 hr manned surveillance, would provide the best opportunity for an effective perimeter inspection. With access any place along the perimeter, the observer would have freedom to view, listen, take nuclear and radiation data, and piece together many pieces of evidence which could otherwise be easily suppressed during the known observation times

DECLASSIFIED

-57-

ENW 1067

under the other alternates. For example, radiation counting times could be continuous in one place if an observer were present to keep the equipment in repair, or counts could be taken every day in repeated locations to accumulate greater statistical accuracy. A 24 hr surveillance team supplied with the gamma and infrared equipment used in the experimental measurements and manned with technically competent and imaginative observers could probably devise means in the field eventually for detecting countermeasures and correlating directions from which trace amounts of radioactivity were released. Actually, visual evidences of vapor condensate and smoke would probably be revealing in themselves if no countermeasures were attempted. Combined with judgment of the numbers of people and amount of material entering the area, they could probably show convincing evidence if a violation occurred. The monitoring equipment discussed would cost on the order of \$25,000 minimum and could be transported in two pickups. However, more sophisticated equipment desirable for gathering maximum information could cost on the order of \$100,000 or more.

Alternate II, in which the observer has freedom of access at any time but has to provide the host with 1 hr notice has a slight disadvantage relative to continuous surveillance because the violator would have sufficient warning to cease otherwise evident activity. On the other hand, the observer would presumably be free to go out to the field any day and at any time of the day and could compile statistical data much as in the case of 24 hr surveillance. The primary advantage is again observer flexibility. The resident observer could also leave equipment operating in the field between visits, such as overnight or over a weekend, to provide him with nearly the equivalent data-gathering capability of the 24 hr manned surveillance case. It would not appear necessary or even desirable in this case to insist on "black box" integrity against tampering and countermeasures, as the observer's frequent access to equipment and data in this case would help to inhibit or reveal such attempts.

Alternate III provides nonresident surveillance with "random" access on seven days warning. If the inspection were made sufficiently often and unpredictably, a potential violator would find it quite inefficient to start the reactor with the possibility that anytime it was started it would have to be down

DECLASSIFIED

-58-

again in a week to avoid detection. The nonresidence requirement would make the overall effectiveness of this alternate correspond, however, to that under the primary ground rules. Inspections would resemble infrequent field experiments rather than permitting the accumulating and analyzing of data of statistical significance possible under the 24 hr surveillance and 1 hr notice alternatives. Furthermore, in the nonresident access cases, it is highly likely that the violator would have shut the reactor down prior to the inspection, anyway, and operating information would be available only if instruments left in the field for recording between inspections were known to be registering reliable data. The question on mechanisms to prevent spoofing of permanent instruments left at the perimeter is referred to the "Black Box" discussion under heading III A. 4 of this report.

The alternative of having the perimeter around only the reactor building, say within 200 ft, and of excluding alternate industrial activity within the perimeter would appear reasonably attractive, especially if heating or air-conditioning of the building were also forbidden in the ground rules. Again, the 24 hr surveillance and resident 1 hr warning systems would provide greatest assurance of detection of operation, as operation would probably be halted by a violator prior to an inspection under the nonresident alternates. The close perimeter raises the possibility of taking ground and air samples around and back from the perimeter as an indicator of operation. Trace analyses would have to be shown to be from the "shutdown" reactor, and it is very unlikely that they could provide bases for estimating interim production within a factor of 100.

Finally, the possibility of flyover was to be considered. Flyover may provide a good chance to detect reactor operation through infrared observations and possibly radiation indications if shielding tolerances around control entries are relatively large as in the case of the Hanford reactors. The flyover would presumably permit a scan to be made of the surrounding area, and the path of effluent heat to its ultimate sink could probably be followed if countermeasures had not been carried out. A flyover might also permit the observation of activities released from reactor operation such as N^{16} , Ar^{41} , tritium, and fission products. Such evidence would not confirm

DECLASSIFIED

-59-

a violation, however, if other reactors in the vicinity were still operating legitimately. As in the case of ground inspection, countermeasures of shielding and baffling within the reactor building and of mixing the effluent flow with that from legitimately operating reactors could seriously limit the reliability of inspection assurance. Assurance of infrared methods would be improved in the flyover case by insistence on no alternate use for the reactor building and no deliberate heating and ventilating.

In conclusion, under the alternate ground rules evidence of violation of a shutdown agreement could be stronger than under the basic ground rules. However, data obtained under any perimeter inspection system (assuming other reactors in the local complex are still operating legitimately) would have to be considered as evidence rather than proof.

IV. ACKNOWLEDGEMENTS

The infrared studies and experiments were carried out and the details reported by D. R. Green of Quantum Electronics Section, Applied Physics and Electronics Department, Battelle-Northwest.

The neutron and gamma spectroscopy measurements were carried out largely by J. R. Bovingdon of Environmental Studies Section, and F. L. Rising of Dosimetry Technology Section, Environmental Health and Engineering Department, Battelle-Northwest. M. R. Wood of Instrumentation Section, Applied Physics and Electronics Department, provided consultation on the design and execution of the experiments and interpretation of results.

Dr. D. P. Granquist of Advanced Concepts and Analysis Section, Mathematics Department, provided consultation on the interpretation of the data and on the feasibility of perimeter inspection in view of available data, potential monitoring improvements and alternatives, and potential countermeasures which might be encountered, and contributed to the drafting of the final report.

G. C. Fullmer, Manager-Instrumentation, Applied Physics and Electronics Department, carried overall responsibility for technical administration of the program and for the final reporting of experimental results and conclusions.

DECLASSIFIED

-60-

BN

APPENDIX

GROUND RULES

The listing of "Preliminary Ground Rules," attached as an appendix to the original AEC request letter⁽¹⁾ is repeated below:

Basic Rules

1. Perimeter inspections are limited to conditions where the building complex containing the reactor is above ground and two full sides of the building complex (or 50% of the building perimeter) must be visible to an inspector standing at ground level from the inspection perimeter. Perimeter is one mile from the reactor building at farthest point (the farthest outer fence line corner at F Reactor is 4500 ft from the reactor building).
2. All devices used by the inspectors would be examined by host countries.
3. Reactor can be in any state of readiness (including loaded with fuel since perimeter inspection could not prevent). Other activity, industrial or otherwise, may go on within perimeter (indicate at what point other activity would prevent effective inspection).
4. Ground surveillance only, with no flyovers permitted.
5. Entire perimeter is available for patrolling.
6. Walk through facility undertaken at beginning to assure it is a reactor.
7. Reactor owner would have ample time to prepare for cheating if desired in advance of initiation of inspection takeover.
8. Reactor owner requested to tell where various key underground facilities run but inspection group cannot dig, etc., to verify; non-disruptive means, such as electronic metal detectors, could be used to verify, however.

(1) A. T. Gifford to A. B. Greninger, "Investigation and Report on the Feasibility of a Perimeter Inspection System for Determining if a Reactor Remains Shutdown," May 10, 1965.

DECLASSIFIED

-61-

NWL-CC-44

10. Environmental sampling allowed only at the perimeter.
11. Other reactors may be operating close by and may use common facilities and a common heat sink.
12. The production achieved between visits (3 months) is not of significance as long as the fact is discovered and, therefore, transmitting instruments not required.

System I

- A. 24-hr manned surveillance. What instruments, if any, are required?

System II

- A. Inspector's travel to perimeter from residence not more than one hour's drive (approximate distance to Richland is 35 miles). Access to perimeter at any time but reactor owner will have notice equal to travel time.

1. Inspector may bring instruments with him, as in truck.
2. Ground mounted instruments available at each visit for his close observation.

System III

- A. Nonresident surveillance with random access. Seven days warning available. If permanent instruments at perimeter, what mechanisms to prevent spoofing?

Systems IA through IIIA

- A. Reconsider all of above if perimeter is around only the specific reactor building (recommend the appropriate distance). In this case, no other industrial activity within perimeter except owner can maintain reactor to any level* desired.

- B. Reconsider above if flyover is permitted, i.e., eliminate Rule 4. In particular, please consider

*"Level" assumed as referring to level of maintenance, not power level.

DECLASSIFIED

- 62 -

BNWL-CC-437

-
1. IR techniques. Since techniques used would be unclassified, commercial unclassified IR systems should be considered first. If these will not be adequate we would then consider desirability of including more advanced systems.
 2. Gamma Spectroscopy Techniques.
-

UNCLASSIFIED

DECLASSIFIED

BNWL-CC-437

INTERNAL DISTRIBUTION

Copy Number

Battelle-Northwest

1	C. A. Bennett
2	G. C. Fullmer
3	G. F. Garlick
4	D. P. Granquist
5	D. R. Green
6	J. J. Jech/J. R. Bovingdon
7	R. S. Paul
8	W. G. Spear/M. R. Wood
9	C. M. Unruh/F. L. Rising
10	D. C. Worlton
11	Technical Information Files

AEC-RLOO

12 - 66	C. R. Qualheim
---------	----------------

DUN

67	T. W. Ambrose/P. C. Jerman
68	R. E. Dunn
69	C. N. Gross/R. K. Wahlen
70	C. D. Harrington/O. C. Schroeder
71	A. R. Maguire/J. W. Baker/ W. G. Westover
72	G. F. Owsley

UNCLASSIFIED

DATE

FILMED

7/12/94

END