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DEVELOPMENT REPORT
JULY 1971

MASTER

INTEGRATED SAFEGUARDS EXPERIMENT

FOURTH QUARTERLY REPORT
APRIL - JUNE 1971

D. C. WADEKAMPER, D. M. BISHOP
AND L. T. HAGIE

U. S. ATOMIC ENERGY COMMISSION
CONTRACT AT(30-1)-68

BREEDER REACTOR DEPARTMENT • GENERAL ELECTRIC COMPANY
SUNNYVALE, CALIFORNIA

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Development Report
July 1971

INTEGRATED SAFEGUARDS EXPERIMENT

Fourth Quarterly Report
April - June

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INTEGRATED SAFEGUARDS EXPERIMENT

Fourth Quarterly Report

April - June 1971

D. C. Wadekamper, D. M. Bishop, and L. T. Hagie

ABSTRACT

Data evaluation and limit of error calculations for passive neutron and replacement calorimetry measurements obtained during both experiments (ISE Campaigns 1 and 2) were completed. Incorporation of these measurements into material balances resulted in two additional plutonium MUF values for ISE Campaign 1. Similar calculations for ISE Campaign 2 resulted in trial material balances for total oxide, plutonium, and uranium. A second plutonium balance was obtained when passive neutron measurements were incorporated into the trial material balances. The present status of the Mechanized Accountability and Criticality System is summarized.

I. INTRODUCTION

The General Electric Company has entered into a contract with the United States Atomic Energy Commission, Contract Number AT(30-1)-68, to support technical activities associated with the Integrated Safeguards Experiment. The program is sponsored by the Office of Safeguards and Materials Management and administration is provided by the Brookhaven Area Office. The definition of program technical objectives as well as technical direction are provided through the Brookhaven National Laboratory - Technical Support Organization.

The purpose of the Integrated Safeguard Experiment is to evaluate the usefulness to safeguards of material balance techniques that employ data based completely on measurements. Normal production and product certification data for nuclear material are being coupled with information obtained from nondestructive assay measurements accomplished with equipment provided on the General Electric portion of the Plant Instrumentation Program. (The purpose of the United States Atomic Energy Commission's Plant Instrumentation Program is to demonstrate the usefulness to safeguards of nondestructive assay measurements on Special Nuclear Material.) The necessary material balance information was compiled under actual fuel fabrication conditions during two processing campaigns. Over-all program objectives were formulated to demonstrate to the nuclear industry the usefulness of material balance accounting for safeguards.

During most of the contract period, Integrated Safeguards Experiment personnel have been on-site at the General Electric Company Vallecitos Nuclear Center, Pleasanton, California. These personnel, Integrated Safeguards Experiment - Technical Representatives, work jointly with General Electric personnel during planning and data evaluation of test experiments.

Pursuant to the program objectives, the Integrated Safeguards Experiment consisted of evaluation of historical data, planning for future testing, and evaluation of the current test data. The following guidelines were established to provide for administration of the program.

Task 1 - Historical Data and Experimental Planning

Task 2 - Experimental Testing

Task 3 - Program Evaluation and Final Report

This is the fourth in a series of quarterly progress reports written in partial fulfillment of Contract Number AT(30-1)-68. The reporting period is April - June 1971. The previous report in this series was GEAP-12114-6.

II. SUMMARY

Work efforts were continued during the reporting period under Brookhaven National Laboratory — Technical Support Organization technical direction to evaluate the data applicable to material balance accounting obtained from the fabrication experiments.

Evaluation of passive neutron and replacement calorimetry data as well as the associated limits of error calculations were completed for both ISE Campaigns. The sodium iodide and germanium lithium scanning of 48 mixed (uranium-plutonium) oxide rods was completed and data evaluation initiated. A summary of the comparison of the material streams measured by net weights and analytical chemistry results with those defined by passive neutron assay is included.

Two plutonium balances were constructed for ISE Campaign 1. The first balance, NDT Balance 1, utilized net weights and analytical chemistry results as well as passive neutron measurements to define each material stream. The balance resulted in significant (at 95% confidence level) plutonium material unaccounted for (MUF) values of 0.89 and 1.41% for enrichments 1 and 2, respectively. The second balance, NDT Balance 2, was prepared with the best available measurements for each material stream. The balance resulted in plutonium MUF values of 1.14 and 1.62% for enrichments 1 and 2, respectively. Both of the latter MUF values were smaller than the associated limits of error.

Trial material balances as well as NDT Balance 1 were completed for ISE Campaign 2. The trial balances resulted in MUF values of -0.01 and 0.09% for total oxide, 0.79 and 0.67% for plutonium, and 1.36 and 1.04% for uranium for enrichments 1 and 2, respectively. All MUF values were larger than the associated limits for error except for the enrichment 1 total oxide MUF. The finalization of NDT Balance 1 resulted in plutonium MUF values of 0.24 and 0.10% for enrichments 1 and 2, respectively. Both of the MUF values were smaller than the associated limits of error. Evaluation of the measurement data indicated NDT Balance 1 was prepared with the best available measurement for each material stream.

All nondestructive assay measurements required by the ISE-2 Nested Sample Experiment which compares analytical chemistry measurements with those obtained by nondestructive assay were completed.

The General Electric developed Mechanized Accountability and Criticality System is summarized.

III. TASK 2 — EXPERIMENTAL TESTING

A. TASK 2A. MATERIAL BALANCE BY FABRICATION CAMPAIGN — ISE CAMPAIGNS 1 AND 2 NONDESTRUCTIVE MEASUREMENTS

Evaluation of all the nondestructive data except gamma rod scan measurements was completed. The evaluation included the determination of the limits of error for each technique.

1. Passive Neutron Assay

a. General

The development of an adequate statistical model for treating coincident neutron assay data was completed. The model modifies the traditional linear count versus mass calibration curve by weighting the count data in the regression to minimize the absolute error. As such, the weighting function is inversely related to the mass of the standard.

b. Equipment

Coincident neutron instrumentation utilized for measurement of scrap and waste-discard materials was furnished as part of the Plant Instrumentation Program (PIP). It consists of 24 BF₃ counters in two circumferential arrays around a central 8-inch diameter, 10-inch high well. A detailed description of the equipment and a summary of its operating performance may be found in GEAP-12114-3, and -5.

c. Calibration Methods

During scrap and waste-discard measurement the following routine standardization methods were utilized:

1. The PIP scrap and waste-discard standards (10 to 15 samples) were counted to establish the calibration curve for a particular test period. Several cases were observed where the range of available standards did not bracket the test samples.
2. On the basis of ISE Campaign 1 calibration test results, daily calibration checks were performed using only standards containing greater than 0.250 gram of Plutonium-240 equivalent.* This requirement excluded all waste-discard and some scrap standards. During the campaigns the calibration procedure was finalized so that appropriate standard counts were control charted throughout the day to test instrument stability. If a drift in the calibration curve were to occur, the entire calibration curve would be redefined using both scrap and waste-discard standards.

d. Data Collection

A test on an individual gallon can size package of ISE scrap or waste-discard material consisted of a 10-minute static count in the life time mode. Fuel scrap and waste-discard standards supplied as part of the PIP and described in the PIP First Quarterly Report, April to June, 1970 (GEAP-12114-1), were utilized for standardization.

e. Data Evaluation

The "F" test technique at 0.95% confidence was used to determine statistically significant day-to-day instrument variations for scrap and waste-discard passive neutron assay data. As a result, assay data were grouped into the following statistically independent periods for purposes of data reduction and subsequent analysis:

ISE Campaign 1

Period		Number of Neutron Tests			
		Standards		Process Material	
		Waste	Scrap	Waste	Scrap
1	October 7-13, 1970	37	9	59	15
2	November 10-13, 1970	27	3	13	1
3	December 1-16, 1970	—	20	—	17
4	December 23-28, 1970	—	18	—	20

ISE Campaign 2

Period					
1	October 7-13, 1970	—	—	—	—
2	November 10-18, 1970	33	3	8	—
3	Nov. 30-Dec. 17, 1970	25	31	13	—
4	Dec. 21 to Dec. 29, 1970	—	46	10	—
5	Dec. 30 to Dec. 31, 1970	—	12	16	—
6	Jan. 4 to Jan. 8, 1971	—	21	7	24
7	Feb. 10 to April 11, 1971	—	12	10	2
8	April 28 to May 4, 1971	6	39	5	6

* As defined in PIP Second Quarterly Report July-September, 1970 GEAP-12114-3, p 5.

f. Data Reduction

Passive neutron assay data were analyzed using a computerized model to calculate the total plutonium content and the associated limit of error for each scrap and waste-discard item (package). Details of the procedure are described in the ISE Third Quarterly Report, December 1970 - March 1971, GEAP-12114-6, Appendix A. The Pu-240 equivalents of the unknowns (packages) within each statistically independent test period were combined for the material balance calculations. The error associated with the unknowns in the combination was determined in the following manner:

$$\sigma^2 (\text{Pu-240 Eq})_{\text{UNK}} = 1/s^2 [\sigma^2 (c) + n^2 \sigma^2 (i) + u^2 \sigma^2 (s) + 2 u n \text{ COVAR} (i, s)]$$

where:

$$\begin{aligned} \sigma^2 (\text{Pu-240 Eq})_{\text{UNK}} &= \text{the variance of the Pu-240 equivalent content of the unknown(s);} \\ s^2 &= \text{slope of calibration curve squared;} \\ \sigma^2 (c) &= \text{the variance of the total coincident counts;} \\ n &= \text{the number of unknown packages;} \\ \sigma^2 (i) &= \text{the variance of the intercept of the calibration curve;} \\ \sigma^2 (s) &= \text{the variance of the slope of the calibration curve;} \\ u &= \text{the total Pu-240 equivalent of the unknown(s);} \\ \text{COVAR} (i, s) &= \text{the covariance between the slope and the intercept of the calibration curve.} \end{aligned}$$

After the determination of the Pu-240 equivalent content (u), the total plutonium content was obtained as follows;

$$(\text{Pu-240})_{\text{UNK}} = (u)(f)$$

which has an associated error given by

$$\sigma^2 (\text{Pu-240})_{\text{UNK}} = (u)^2 \sigma^2 (f) + (f)^2 \sigma^2 (u)$$

and

$$(\text{Total Pu})_{\text{UNK}} = (\text{Pu-240})_{\text{UNK}} / P$$

with an associated error of

$$\sigma^2 (\text{Total Pu})_{\text{UNK}} = \sigma^2 (\text{Pu-240})_{\text{UNK}} (P)^2 + \sigma^2 (P) (\text{Pu-240})_{\text{UNK}}^2 / P^4$$

where;

(Pu-240)_{UNK} = the Pu-240 content of the unknown(s); (f) = the Pu-240 equivalency factor of the unknown(s); (Total Pu)_{UNK} = the total plutonium content of the unknown(s); P = the isotopic abundance of Pu-240 in the unknown(s).

The above data analysis method does not account for the following systematic errors:

- (1) Inaccuracies associated with the spontaneous fission ratios of the plutonium isotopics;
- (2) Inaccuracies associated with the Plutonium-240 equivalent content of the PIP Standards.

g. Data Summary

A summary of the material streams measured by net weight and analytical chemistry results as well as passive coincident neutron assay techniques is presented in Table 1. Assuming that no bias exists in the measurement techniques, one would expect that the plutonium content of the clean sintered scrap (excess product and material of the same plutonium-to-oxide ratio) and the green recycle (unprocessed green powder) determined by both measurement techniques would overlap. Examination of Table 1 indicates that the data followed the expected pattern except for ISE Campaign 2 enrichment 1 results. No apparent reason was found for the difference.

TABLE 1. ISE Material Stream Comparison

ISE Campaign 1	Accountability Value			NDT Value		
	Total Pu (g)	LE (g) ^(a)	LE (%)	Total Pu (g)	LE (g) ^(a)	LE (%)
<u>Enrichment 1</u>						
Clean Sintered Scrap	214.2	0.85	0.4	213.7	5.61	2.6
Green Scrap ^(b)	34.0	0.54	1.6	35.0	0.74	2.1
Dirty Sintered Scrap ^(b)	10.7	0.04	0.4	9.8	0.64	6.5
Waste-Discards (Green & Sintered) ^(b)	4.36 ^(c)	—	—	11.4	0.04	3.5
<u>Enrichment 2</u>						
Green Recycle	67.2	1.03	1.5	65.2	1.77	2.7
Clean Sintered Scrap	186.2	0.66	0.4	193.8	7.38	3.8
Green Scrap ^(b)	52.9	0.20	0.4	52.3	1.30	2.5
Dirty Sintered Scrap ^(b)	7.9	0.02	0.3	7.3	0.48	6.5
Waste-Discards (Green & Sintered) ^(b)	4.4 ^(c)	—	—	9.2	0.26	2.8
<u>Miscellaneous</u>						
Absolute Filters	0.00	—	—	6.0	2.18	36.5
Waste	0.07	—	—	1.7	0.20	1.2
<u>ISE Campaign 2</u>						
<u>Enrichment 1</u>						
Green Recycle	76.7	2.01	2.6	70.7	1.20	1.7
Clean Sintered Scrap	73.9	0.29	0.4	69.3	1.76	2.5
Green Scrap ^(b)	28.5	0.75	2.6	28.9	0.44	1.5
Dirty Sintered Scrap ^(b)	13.3	0.06	0.5	12.6	0.22	1.7
Waste-Discards (Green & Sintered) ^(b)	7.0 ^(c)	—	—	10.1	0.90	8.9
<u>Enrichment 2</u>						
Clean Sintered Scrap	116.6	0.59	0.5	117.5	1.42	1.2
Green Scrap ^(b)	13.6	1.30	9.6	14.2	0.21	1.5
Dirty Sintered Scrap ^(b)	15.4	0.08	0.5	14.8	0.29	2.0
Waste-Discards (Green & Sintered) ^(b)	3.3 ^(c)	—	—	8.0	1.50	18.8
<u>Miscellaneous</u>						
Absolute Filters	0.00	—	—	2.2	0.70	32.0

(a) 95% Confidence

(b) The plutonium content was obtained by Multiplying the net weight (which may not be 100% SNM) by the appropriate plutonium-to-oxide ratio.

(c) Includes some estimated values.

The plutonium content of green scrap (partially processed green powder) and dirty sintered scrap (sintered product materials which has been altered or downgraded in chemical composition) determined by the two measurement techniques agreed (limits of error overlap) a majority of the time. The agreement was not expected because some of the material streams had been downgraded during processing. The fact was demonstrated by the dirty sintered scrap results in Table 1, *i.e.*, the plutonium content was always larger when accountability values were assigned by using net weights and analytical chemistry results.

Examination of the plutonium content of the waste-discards indicated that the accountability values (both estimated and measured) were a factor of 2 lower than the passive neutron assay values. The passive neutron assay data for the absolute filters indicated that the plutonium content of absolute filters was grossly underestimated.

The data presented in Table 1 indicated that nondestructive assay techniques are valuable tools which can be used to obtain measured material balances. The techniques provided meaningful measurements for previously unmeasured or inadequately measured material streams.

2. Calorimetry

a. Replacement Calorimetry Measurements

Replacement calorimetry measurements were made on all the feed for ISE Campaigns 1 and 2. The results of the measurements were described in the ISE Second Quarterly Report, September–November, 1970 GEAP-12114-4, pp. 8–10 and 28.

b. Error Analysis

The effect of isotopic analytical errors (resulting from current capabilities) on replacement calorimetry assay results were determined. The isotopic contribution to the total errors for ISE Campaign 1 and 2 feed material were 4.3 and 7.8%, respectively. The contributions for specific isotopes are:

Isotope	ISE Campaign 1 (A0122)			ISE Campaign 2 (A0146)		
	Abundance ^(a) (%)	Error (%)	Propagated Error ^(b) (%)	Abundance ^(a) (%)	Error (%)	Propagated Error ^(b) (%)
Pu-238	0.104 ^(c)	10	1.74	0.249	10	2.66
Pu-239	87.12	0.04	0.02	75.65	0.04	0.01
Pu-240	10.12	0.1	0.02	18.48	0.1	0.03
Pu-241	2.38	0.2	0.00	4.50	0.2	0.01
Pu-242	0.28	0.6	0.00	1.13	0.4	0.00
Am-241	0.278 ^(b)	27.2	2.56	0.860 ^(b)	27.2	5.06
Total Systematic Error			4.3%			7.8%

(a) Minor discrepancies between the isotopic abundances utilized for calorimetry and neutron measurements resulted from the use of additional data which was available during reduction of the neutron assay results.

(b) Propagated error contribution = isotopic abundance X analytical error X watt/gm constant for the applicable isotopes.

(c) Vendor data corrected to date of calorimetric measurement.

It should be noted that the only significant errors are those associated with the Pu-238 and Am-241 analyses. Since the total error in the isotopic determination was large compared to other errors, it was considered as the limit of errors for calorimetry measurements.

3. Gamma Rod Scanning

a. Sodium Iodide Testing

The gamma scanning of 48 product fuel rods using the four channel technique developed as part of the PIP* was completed. Four isotopes (Pu-239, Pu-241, Am-241, and U-238) contribute to the four spectral channel techniques. Within the limiting assumptions of the technique, the count rate in each of the four channels with a given sample (i) is as follows:

$$c_1^{(i)} = a_{11} M_i \text{ Pu-239} + a_{12} M_i \text{ Pu-241} + a_{13} M_i \text{ Am-241} + a_{14} M_i \text{ U-238}$$

$$c_2^{(i)} = a_{21} M_i \text{ Pu-239} + a_{22} M_i \text{ Pu-241} + a_{23} M_i \text{ Am-241} + a_{24} M_i \text{ U-238}$$

$$c_3^{(i)} = a_{31} M_i \text{ Pu-239} + a_{32} M_i \text{ Pu-241} + a_{33} M_i \text{ Am-241} + a_{34} M_i \text{ U-238}$$

$$c_4^{(i)} = a_{41} M_i \text{ Pu-239} + a_{42} M_i \text{ Pu-241} + a_{43} M_i \text{ Am-241} + a_{44} M_i \text{ U-238}$$

where

$c_z^{(i)}$ = The observed gross count in channel (z) resulting from sample (i) during a fixed counting time;

a_{jk} = calibration constants empirically determined from standards;

M_i = the mass in grams of the contributing isotope.

By inverting this matrix, the masses of each of the four isotopes in sample (i) were calculated. An example for Pu-239 follows:

$$M_{\text{Pu-239}}^{(i)} = b_{11} c_1^{(i)} + b_{12} c_2^{(i)} + b_{13} c_3^{(i)} + b_{14} c_4^{(i)}$$

Fuel in the 48 fuel rods evaluated were of the following nominal physical and chemical characteristics:

<u>Group</u>	<u>Rod Serial No.</u>	<u>Description</u>
1	VP-1 to 10	Solid fuel, 2.38% Pu/MO ₂ , A0146 feed material
2	VP-13 to 26	Solid fuel, 3.42% Pu/MO ₂ , A0122 feed material
3	VP-31 to 40	Annular fuel, 2.58% Pu/MO ₂ , A0146 feed material
4	VP-43 to 56	Annular fuel, 3.54% Pu/MO ₂ , A0122 feed material

Data collection was performed with a 2 x 2 inch sodium iodide detector and a 1024 channel analyzer.

Subsequent data reduction was performed by using the first rod in each of the four groups as a standard. Each standard was run repeatedly throughout the test period and the data used to establish calibration constants.

*PIP Second Quarterly Report, July - September 1970 GEAP-12113-3, p 2.

Joint efforts between Integrated Safeguards Experiment – Technical Representative and General Electric personnel resulted in the empirical determination of the random components of the limits of error for the sodium iodide rod scan data. No attempt was made to determine the systematic components of the limits of error. The principle sources of error resulted from standardization and experimental counting. An estimate of the error for each rod was established as follows:

1. With a given set of simultaneous equations, obtained from the four channel counting technique, successive scans were taken of a sample rod. The Pu-239 mass in the sample rod was calculated for each scan and the variance of the set determined. This variance, LE-1, was the first portion of the total limit of error for the Pu-239 mass of a single scan.
2. For a given set of standards, successive scans were taken and the simultaneous equation constants necessary to obtain the known Pu-239 mass calculated. The variance of the constants, LE-2, was a second portion of the total limit of error for the Pu-239 mass of a single scan. The resultant error is common to all scan data which utilize a particular set of equation constants.

The 48 fuel rods involved in the ISE were then divided into four data sets by isotopics and fuel forms. The total Pu-239 mass of each set was obtained by adding the individual rod masses. The contributions of LE-1 and LE-2 to the total limit of error were determined by combining the individual rod errors as follows:

$$\text{Error Pu-239} = \sum_{i=1}^N \text{Mass Pu-239} \pm [N(\text{LE-1})^2 + N(\text{LE-2})^2]^{1/2}$$

where N = the number of rods in an individual set. Preliminary evaluation of empirical test results from all the rod scan data sets indicated an over-all two sigma limit of error of approximately 4%.

b. Germanium Lithium Testing

The gamma scanning of 48 product, and 5 PIP standard fuel rods was completed with direct assistance from Integrated Safeguards Experiment-Technical Representatives. Instrumentation utilized for this experiment included a 50-cc germanium (lithium) detector and a 1024-channel analyzer which was purchased as part of the Plant Instrumentation Program. The technique utilized for this testing is outlined as follows:

1. The 0.208-MeV peak resulting from U-237 (a daughter of Pu-241) and the 0.414-MeV complex of peaks resulting from Pu-239 were integrated and corrected by subtracting adjacent back ground regions.
2. A complete printout of the spectral region of interest (0.1 to 0.6 MeV) was made for each rod to permit subsequent evaluation of the data on a more detailed basis.
3. Single-channel analyzers were calibrated to allow to strip chart recording to be made of each rod. One system recorded Am-241 isotopic variations while another monitored high energy spectra above approximately 0.6 MeV.
4. A pulse generator was utilized for calibration.

Data reduction is progressing as a joint effort with Integrated Safeguards Experiment-Technical Representative personnel.

B. TASK 2A. MATERIAL BALANCE BY FABRICATION CAMPAIGN – ISE CAMPAIGN 1

1. General

Two plutonium balances were obtained by incorporating the passive neutron and replacement calorimetry measurements with some of the analytical chemistry measurements utilized in the traditional material balances*. The first balance, NDT Balance 1, utilized passive neutron measurements to define material streams which were inadequately measured by net weights and analytical chemistry results. The second balance, NDT Balance 2, was based on the best available measurement for each material stream. Both balances were prepared for enrichments 1 and 2, plutonium-to-oxide ratios of 3.54 and 3.42%, respectively. Each enrichment consisted of two master blends which were treated separately and combined in the balances.

2. NDT Balance 1

The first step in preparing NDT Balance 1 was to separate the individual oxide weights obtained during fuel fabrication into subgroups by plutonium-to-oxide ratio. Only the oxide weights which represented material that was not altered by addition of unknown or unmeasured material were considered. The oxide weights were summed by subgroups and multiplied by the appropriate plutonium-to-oxide ratio. A summary of the plutonium-to-oxide ratios utilized during material balance calculations is given in Table 2. The following material streams were defined by oxide weights and plutonium-to-oxide ratios – total plutonia feed, excess plutonia feed, product, samples, green recycle, and clean sintered scrap.

TABLE 2. ISE Campaign 1 – Analytical Chemistry Summary

Identity	Material Type	Enrichment	Mean (gm/gm)	Number Of Samples	Standard Deviation (gm/gm)	Coefficient of Variation (%)	Standard Error of Mean (gm/gm)
A0122	PuO ₂ Powder	1 and 2	0.8713 ^(a)	5	0.00516	0.59	0.00231
M0094	Green MO ₂ Powder	1	0.0347	3	0.00101	2.91	0.00058
M0095	↓	1	0.0348	3	0.00035	1.01	0.00020
M0096	↓	2	0.0341	3	0.00035	1.03	0.00020
M0098	↓	2	0.0337	3	0.00021	0.62	0.00012
M0094	Sintered MO ₂ Powder	1	0.0354	19	0.00035	0.99	0.00008
M0095	↓	1	0.0354	15	0.00049	1.38	0.00013
M0096	↓	2	0.0341	17	0.00033	0.97	0.00008
M0098	↓	2	0.0343	17	0.00022	0.64	0.00005

(a) Pu/PuO₂ all others are Pu/MO₂

The balances were completed by defining material streams which were inadequately measured by net weights on analytical chemistry results with passive neutron assay techniques. The following material streams were defined in this fashion – process losses (waste-discards which includes processing waste, vacuum cleaner bags, filters and floor sweeps), green scrap, and dirty sintered scrap.

*ISE, Second Quarterly Report, September–November 1970, GEAP-12114-4, pp. 10–13.

The plutonium-to-oxide ratio used to define the plutonia feed was difficult to determine because of moisture absorption for both samples and feed material. The dried feed measurements were supported by calorimetry data (chemical assay—5847.3 grams plutonium and calorimetry—5854.5 grams plutonium). The weight of the excess plutonia feed was reduced by a ratio of starting weight to the weight removed from the can (starting weight plus absorbed moisture) to account for moisture adsorption.

The limits of error for the material streams measured by net weights and analytical chemistry results were combined so the standard error of the appropriate plutonium-to-oxide ratio was propagated with the error obtained from summing the weights of the same composition. Propagation of the limits of error in this manner eliminates the covariance term which results from using the same plutonium-to-oxide ratio to define more than one material stream. One would expect the covariance term to be positive in nature which would increase the limit of error for the balance. The limits of error for the passive neutron measurements were combined so the individual errors on a measurement were combined for statistically separate test periods. The errors between test periods were then combined in a random manner to obtain the limits of error for all the passive neutron measurements.

Since the absolute filters were changed on a campaign basis, the amount of plutonium measured in the filters was divided equally between the two enrichments. The limits of error for these measurements were obtained by multiplying the percent limit of error by the plutonium allocated to each enrichment.

The material balances (NDT Balance 1) for plutonium and the associated limits of error for each material stream as well as MUF are presented in Table 3. The balances resulted in plutonium MUF values of 0.89 and 1.41% for enrichments 1 and 2, respectively. The MUF values are larger than the associated limits of error. This occurrence in material balance accounting is usually due to one or more of the following: (a) unidentified bias in the plutonium measurement, (b) inaccurate measurement of material, or (c) unaccounted for loss or diversion of material. The moisture adsorption problems with the plutonia feed for ISE Campaign 1 indicated that an inaccurate measurement was the most likely explanation.

Although the plutonium MUF values are larger than the associated limits of error, they are smaller than the values from the trial material balances (1.40 and 1.74% for enrichments 1 and 2, respectively). A reduction in the plutonium MUF values occurred because previous unmeasured material was included in the balance. The larger limits of error values resulted from incorporation of the passive neutron assay data and their uncertainties into the material balances. A summary of the passive neutron assay data and their associated limits of error can be found in Section A.1.

3. NDT Balance 2

To prepare a material balance for ISE Campaign 1 utilizing the best available measurement data, it was necessary to obtain plutonia feed measurements that were not affected by moisture adsorptions. The desired information for the plutonia stream was obtained by replacement calorimetry. The details of this measurement method and its associated limits of error are described in Section A.2.

Since replacement calorimetry measurements were made on all feed packages before powder blending, the plutonium content of the feed was available. A calorimetry measurement on the excess plutonia was made only after the completion of the campaign (both enrichments). As a result, the excess plutonia value for enrichment 1 was determined empirically. The value was obtained by multiplying the oxide weight of the plutonia by an adjusted plutonia-to-oxide ratio which was corrected for the moisture adsorption in the excess plutonia. Since all the calorimetry measurements were based on the same isotopic determinations, the limit of error values were obtained by multiplying the relative error associated with the measurements by the amount of plutonia used in the enrichment (feed input minus excess).

The NDT Balance 2 was prepared by replacing the plutonia measurements based on net weights and analytical chemistry results in NDT Balance 1 by calorimetry measurements. The material balance and the associated limits of error for each material stream as well as MUF are presented in Table 4. The balances resulted in plutonium MUF values of 1.14 and 1.62% for enrichments 1 and 2, respectively. The associated limits of error are a factor of 2 to 3 larger than the MUF values. The limits of error which result from the large uncertainty on the calorimetry measurements of the plutonia feed (uncertainties in the Pu-238 and Am-241 isotopic determinations) prevent the detection of the material loss observed in the previous material balances.

TABLE 3. ISE Campaign 1 — Material Balance (NDT Balance 1)

Enrichment 1 — 3.54% Pu Content, %				Enrichment 2 — 3.42% Pu Content, %			
Stream	Metal Content	Limits of Error ^(a)		Stream	Metal Content	Limits of Error ^(a)	
	Pu, gm	Pu, gm	%		Pu, gm	Pu, gm	%
Feed (F)				Feed (F)			
Plutonia	2570.9	18.95	0.74	Plutonia	2603.9	19.19	0.74
Product (P)	1960.5	9.08	0.46	Product (P)	2095.6	5.94	0.28
Measured Discards (MD)				Measured Discards (MD)			
Green Samples				Green Samples			
Plutonia Feed	12.3	0.23	1.87	Plutonia Feed	12.9	0.43	3.33
Mixed Oxide	0.2	0.02	10.00	Mixed Oxide	0.5	0.03	6.00
Sintered Samples	14.8	0.08	0.54	Sintered Samples	13.8	0.05	0.36
Process Losses ^(b)	15.2	1.10	7.24	Process Losses ^(b)	13.0	1.13	8.69
Inventory (I)				Inventory (I)			
Plutonia	286.1 ^(c)	2.12	0.74	Plutonia	118.2 ^(c)	0.89	0.75
Green Recycle	—	—	—	Green Recycle	67.2	1.03	1.53
Green Scrap	35.0	0.74	2.11	Green Scrap	52.3	1.30	2.49
Dirty Sintered Scrap	9.8	0.64	6.53	Dirty Sintered Scrap	7.3	0.48	6.58
Clean Sintered Scrap	214.2	0.88	0.41	Clean Sintered Scrap	186.2	0.74	0.39
Material Unaccounted For ^(d) (MUF)	22.8	19.58 ^(e)		Material Unaccounted for ^(d) (MUF)	36.9	19.47 ^(e)	
% MUF ^(f)	0.89			% MUF ^(f)	1.41		

(a) All quantities at 95% confidence

(b) Includes absolute filter data which was divided equally between enrichments

(c) Corrected for moisture equilibration

(d) $MUF = F - (P + MD + I)$ for appropriate values (assumes beginning inventory was zero)

(e) Limits of error corrected for covariance terms included in the body of the table

(f) Based on input

TABLE 4. ISE Campaign 1 — Material Balance (NDT Balance 2)

Enrichment 1 — 3.54% Pu Content, %				Enrichment 2 — 3.42% Pu Content, %			
Stream	Metal Content	Limits of Error ^(a)		Stream	Metal Content	Limits of Error ^(a)	
	Pu, gm	Pu, gm	%		Pu, gm	Pu, gm	%
Feed (F)				Feed (F)			
Plutonia	2578.0	111.11	4.31	Plutonia	2608.2	112.41	4.31
Product (P)	1960.5	9.08	0.46	Product (P)	2095.6	5.94	0.28
Measured Discards (MD)				Measured Discards (MD)			
Green Samples				Green Samples			
Plutonia Feed	12.3	0.23	1.87	Plutonia Feed	12.9	0.43	3.33
Mixed Oxide	0.2	0.02	10.00	Mixed Oxide	0.5	0.03	6.00
Sintered Samples	14.8	0.08	0.54	Sintered Samples	13.8	0.05	0.36
Process Losses ^(b)	15.2	1.10	7.24	Process Losses ^(b)	13.0	1.13	8.69
Inventory (I)				Inventory (I)			
Plutonia	286.4 ^(c)	12.47	4.31	Plutonia	117.2	5.05	4.31
Green Recycle	—	—	—	Green Recycle	67.2	1.03	1.53
Green Scrap	35.0	0.74	2.11	Green Scrap	52.3	1.30	2.49
Dirty Sintered Scrap	9.8	0.64	6.53	Dirty Sintered Scrap	7.3	0.48	6.58
Clean Sintered Scrap	214.2	0.88	0.41	Clean Sintered Scrap	186.2	0.74	0.39
Material Unaccounted For ^(d) (MUF)	29.6	98.77 ^(e)		Material Unaccounted For ^(d) (MUF)	42.2	107.55 ^(e)	
% MUF ^(f)	1.14			% MUF ^(f)	1.62		

(a) All quantities at 95% confidence

(b) Includes absolute filter data which was divided equally between enrichments

(c) Value calculated from net weight and adjusted plutonium-to-oxide ratio

(d) MUF = F — (P + MD + I) for appropriate values (assumes beginning inventory was zero)

(e) Limits of error corrected for covariance terms included in the body of the table

(f) Based on input

Even though the plutonia MUF values are smaller than the associated limits of error, they were larger than those obtained in NDT Balance 1, 0.89 and 1.14% for enrichments 1 and 2, respectively. The increased MUF values were a result of the slightly larger plutonia input values obtained from the calorimetry measurements.

C. TASK 2A. MATERIAL BALANCE BY FABRICATION CAMPAIGN – ISE CAMPAIGN 2

1. General

Trial material balances similar to those calculated for ISE Campaign 1* were completed for total oxide, plutonium, and uranium. A plutonium material balance, NDT Balance 1, was prepared which utilized passive neutron measurements to define material streams inadequately measured by net weights and analytical chemistry results. Examination of additional measurements indicated that NDT Balance 1 was prepared with the best available measurements for each material stream.

2. Trial Material Balances

Before the evaluation of the nondestructive assay measurements, trial material balances were calculated for enrichments 1 and 2, 2.58 and 2.38% plutonium-to-oxide ratio, respectively. Each enrichment consisted of one master blend. The format of the balances was similar to the historical balances,[†] however, only total oxide streams which were measured (weighed) were included. Any unmeasured stream was considered MUF.

The trial material balances were prepared by separating the individual oxide weights obtained during fuel fabrication into subgroups of the same metal-to-oxide ratio. The oxide weights were summed by subgroup and multiplied by the appropriate metal-to-oxide ratio to obtain the uranium and plutonium balances. A summary of the plutonium-to-oxide ratios utilized during the material balance calculations is given in Table 5. It should be noted the trial balances depart from a true measured balance as follows:

1. The metal-to-oxide ratios obtained from blended powders (pre-production samples) were used to characterize all unsintered material, *i.e.*, green scrap and green process losses.
2. The metal-to-oxide ratios obtained from sintered pellets were used to characterize all sintered material, *i.e.*, sintered scrap, sintered process losses, and product.
3. The total oxide weights for process losses (vacuum cleaner bags and pre-filters), part of the green scrap and the dirty sintered scrap, may include some impurities other than nuclear material.
4. A theoretical oxide-to-metal ratio was used to obtain the uranium content of the feed.

TABLE 5. ISE Campaign 2 – Analytical Chemistry Summary

Identity	Material Type	Enrichment	Mean (gm/gm)	Number Of Samples	Standard Deviation (gm/gm)	Coefficient of Variation (%)	Standard Error of Mean (gm/gm)
A0146	PuO ₂ Powder	1 and 2	0.8503 ^(a)	8	0.00228	0.27	0.00081
M0100	Green MO ₂ Powder	1	0.0256	3	0.00027	1.05	0.00016
M0101	Green MO ₂ Powder	2	0.0232	3	0.00089	3.83	0.00051
M0100	Sintered MO ₂ Powder	1	0.0258	20	0.00022	0.85	0.00005
M0101	Sintered MO ₂ Powder	2	0.0238	19	0.00025	1.05	0.00006

(a) Pu/PuO₂, all others are Pu/MO₂

*ISE, Second Quarterly Report, September – November 1970, GEAP-12114-4, pp. 10-11.

[†]Ibid., pp. 3-4.

The moisture adsorption of the plutonia feed experienced during ISE Campaign 1 was eliminated by equilibrating the plutonia feed prior to the initiation of ISE - Campaign 2.*

The trial material balances for total oxide, plutonia, and uranium are shown in Table 6. The balances resulted in MUF values of -0.01 and 0.09% for total oxide, 0.79 and 0.67% for plutonium, and 1.36 and 1.04% for uranium for enrichments 1 and 2, respectively. The limits of error for each stream were combined such that the error in the appropriate metal-to-oxide ratio was propagated with the error obtained from the summation of individual weights of the same concentration. The limit of error calculations for enrichments 1 and 2 are presented in Table 7. All the MUF values except the total oxide for enrichments 1 were larger than the associated limits of error. The most plausible explanation for the significant MUF values was that some material streams were considered as MUF because they were inadequately measured by net weights and analytical chemistry results.

3. NDT Balance 1

The balances were prepared identically to those for ISE Campaign 1 (Section B.2) except for the manner in which plutonium isotopic errors were propagated between individual test periods. Examination of the ISE Campaign 1 data indicated an uncorrected covariance term existed in the data reduction model. The error propagation techniques utilized for ISE Campaign 2 were modified to eliminate the covariance term. In the ISE Campaign 2 balances the analytical chemistry measurements were used to define the plutonia feed because the equilibration step before initiation of fuel processing, eliminated the moisture adsorption problem. Since the equilibrated plutonia was used as the starting point of the campaign, any material which was lost during the equilibration will not be accounted for in the material balance calculations.

The material balance for plutonium and the associated limits of error for each material stream as well as MUF are shown in Table 8. The balances resulted in plutonium MUF values of 0.24 and 0.10% for enrichments 1 and 2, respectively. Since the range on the limits of error for MUF include zero, no significant loss of material could be detected because of the measurement uncertainties in the system. The MUF values of 4.0 grams in 1641.7 grams plutonium (enrichment 1) and 1.2 grams in 1198.7 grams plutonium (enrichment 2) indicates the degree of control achieved during ISE Campaign 2 is sufficient to demonstrate that material balance accounting is a sensitive safeguards tool.

The plutonia MUF values for NDT Balance 1 were much smaller than those in the trial balance, 0.79 and 0.67% for enrichments 1 and 2, respectively. The incorporation of the nondestructive assay measurements in the material balance accounted for material that was previously considered as MUF.

Examination of all measurement data for each material stream indicated the best available measurements were used in NDT Balance 1. As a result, NDT Balance 2 was not prepared for ISE Campaign 2.

4. ISE-2 NDT Nested Sample Experiment

The passive neutron measurements required by the experimental test design were completed. The measurements, coupled with those completed during the last reporting period,[†] will be used to compare the plutonium content of samples determined by analytical chemistry, neutron assay, and gamma counting measurement techniques. Analytical chemistry was initiated on the samples as defined in the test design.

Joint discussions between the Integrated Safeguards Experiment - Technical Representatives and General Electric personnel resulted in the establishment of procedures for the reduction of gamma (NaI) and neutron (coincident) counting data. The gamma data will be normalized using calibration data on standards generated before and after measurement of groups of five pellet samples. The neutron data will be normalized using calibration data on standards

*ISE Second Quarterly Report, December 1970 - March 1971, GEAP-12114-4, p. 18.

†ISE Third Quarterly Report, December 1970 - March 1971, GEAP-12114-6.

TABLE 6. ISE Campaign 2 — Material Balance (Trial)

Enrichment 1 — 2.58% Pu Content, %				Enrichment 2 — 2.38% Pu Content, %			
Stream	Total Oxide, gm	Pu, gm	U, gm	Stream	Total Oxide, gm	Pu, gm	U, gm
Feed (F)				Feed (F)			
Plutonia	1930.7	1641.7	—	Plutonia	1409.0	1198.1	—
Urania	48808.6	—	42707.5 ^(a)	Urania	54922.7	—	48057.4 ^(a)
Processing Changes (PC)	753.1	—	—	Processing Changes (PC)	836.5	—	—
Product (P)	39260.5	1012.5	33394.2	Product (P)	43424.8	1034.8	37192.5
Measured Discards ^(b) (MD)				Measured Discards ^(b) (MD)			
Green Samples				Green Samples			
Plutonia Feed	19.1	16.2	—	Plutonia Feed	2.0	1.7	—
Mixed Oxide	3.0	0.1	2.5	Mixed Oxide	3.0	0.1	2.5
Sintered Samples	345.0	8.9	293.5	Sintered Samples	233.4	5.6	199.9
Process Losses	151.8	3.9	128.0	Process Losses	96.1	2.3	81.7
Inventory (I)				Inventory (I)			
Plutonia	466.5	396.7	—	Plutonia	—	—	—
Urania	2249.6	—	1968.4	Urania	5510.9	—	4822.0
Green Scrap	4113.9	105.2	3463.9	Green Scrap	586.5	13.6	496.8
Dirty Sintered Scrap	514.3	13.3	437.5	Dirty Sintered Scrap	646.3	15.4	553.5
Clean Sintered Scrap	2866.8	73.9	2438.4	Clean Sintered Scrap	4890.8	116.6	4207.7
Material Unaccounted For ^(c) (MUF)	-4.3	11.0	581.1	Material Unaccounted for ^(c) (MUF)	51.4	8.0	500.8
% MUF ^(d)	0.01	0.67	1.36	% MUF ^(d)	0.09	0.67	1.04

(a) Based on theoretical uranium-to-oxide values

(b) Excludes processing waste awaiting nondestructive assay

(c) $MUF = F - (PC + MD + I)$ for appropriate values (assumes beginning inventory was zero)

(d) Based on input

TABLE 7. ISE Campaign 2 — Limits of Error^(a) for Material Balance (Trial)

Enrichment 1 — 2.58% Pu Content, %							Enrichment 2 — 2.38% Pu Content, %						
Stream	Total Oxide		Plutonium		Uranium		Stream	Total Oxide		Plutonium		Uranium	
	(gm)	(%)	(gm)	(%)	(gm)	(%)		(gm)	(%)	(gm)	(%)	(gm)	(%)
Feed							Feed						
Plutonia	0.59	0.03	3.72	0.23	—	—	Plutonia	0.37	0.03	2.71	0.23	—	—
Urania	0.49	0.00	—	—	427.07 ^(b)	1.00	Urania	0.53	0.00	—	—	480.57 ^(b)	1.00
Process Changes	5.61	0.74	—	—	—	—	Process Changes	5.78	0.65	—	—	—	—
Product	1.12	0.00	3.93	0.39	91.48	0.27	Product	1.03	0.00	5.21	0.50	41.26	0.11
Measured Discards							Measured Discards						
Green Samples							Green Samples						
Plutonia	0.54	2.83	0.46	2.84	—	—	Plutonia	0.48	24.00	0.41	24.12	—	—
Mixed Oxide	0.24	8.00	0.01	10.00	0.20	8.00	Mixed Oxide	0.24	8.00	0.01	10.00	0.22	8.00
Sintered Samples	1.15	0.33	0.04	0.45	1.20	0.41	Sintered Samples	1.04	0.45	0.04	0.71	0.92	0.46
Process Losses	1.52	1.00	0.10	2.57	1.92	1.50	Process Losses	2.05	2.15	0.16	6.96	2.35	2.88
Inventory							Inventory						
Plutonia	0.14	0.03	0.90	0.23	—	—	Plutonia	—	—	—	—	—	—
Urania	0.35	0.02	—	—	22.49	1.00	Urania	0.37	0.01	—	—	55.11	1.24
Green Scrap	0.91	0.02	2.76	2.62	43.74	1.26	Green Scrap	0.68	0.12	1.30	9.56	3.89	0.78
Dirty Sintered Scrap	0.97	0.19	0.06	0.45	1.46	0.33	Dirty Sintered Scrap	0.94	0.15	0.08	0.52	1.01	0.18
Clean Sintered Scrap	2.47	0.05	0.29	0.39	6.80	0.28	Clean Sintered Scrap	1.07	0.02	0.59	0.52	4.74	0.11
Material Unaccounted For ^(c)	6.42		5.90		421.97		Material Unaccounted For ^(c)	6.43		6.67		435.28	

(a) All quantities at 95% Confidence

(b) Assumed standard error on nominal uranium assay of $\pm 0.5\%$ relative

(c) Limits of error corrected for covariance terms included in the body of the table

TABLE 8. ISE Campaign 2 — Material Balance (NDT Balance 1)

Enrichment 1 — 2.58% Pu Content, %				Enrichment 2 — 2.38% Pu Content, %			
Stream	Metal Content	Limits of Error ^(a)		Stream	Metal Content	Limits of Error ^(a)	
	Pu, gm	Pu, gm	%		Pu, gm	Pu, gm	%
Feed (F)				Feed (F)			
Plutonia	1641.7	3.72	0.23	Plutonia	1198.1	2.71	0.23
Product (P)	1012.5	3.93	0.39	Product (P)	1034.8	5.21	0.50
Measured Discards (MD)				Measured Discards (MD)			
Green Samples				Green Samples			
Plutonia Feed	16.2	0.46	2.84	Plutonia Feed	1.7	0.41	24.12
Mixed Oxide	0.1	0.01	10.00	Mixed Oxide	0.1	0.01	10.00
Sintered Samples	8.9	0.04	0.45	Sintered Samples	5.6	0.04	0.71
Process Losses ^(b)	11.2	0.97	8.66	Process Losses ^(b)	9.1	1.54	16.92
Inventory (I)				Inventory (I)			
Plutonia	396.7	0.90	0.23	Plutonia	—	—	—
Green Recycle	76.7	2.01	2.62	Green Recycle	—	—	—
Green Scrap	28.9	0.44	1.52	Green Scrap	14.2	0.21	1.48
Dirty Sintered Scrap	12.6	0.22	1.75	Dirty Sintered Scrap	14.8	0.29	1.96
Clean Sintered Scrap	73.9	0.29	0.39	Clean Sintered Scrap	116.6	0.59	0.51
Material Unaccounted For ^(c) (MUF)	4.0	5.64 ^(d)		Material Unaccounted For ^(c) (MUF)	1.2	6.64 ^(d)	
% MUF ^(e)	0.24			% MUF ^(e)	0.10		

(a) All quantities at 95% confidence

(b) Includes absolute filter data which was divided equally between enrichments.

(c) MUF = F — (P + MD + I) for appropriate values (assumes beginning inventory was zero) (e)

(d) Limits of error corrected for covariance terms included in the body of the table.

Based on input

generated before and after measurement of groups of two pellets. A preliminary evaluation of the test data resulted in the following analytical precisions:

<u>Sample</u>	<u>Test Method</u>	<u>Precision (%)</u>
Whole Pellet	NaI - 0.108 MeV	0.8
	NaI - 0.414 MeV	0.6
	Coincident Neutron	0.6
Half Pellets	NaI	-
	Coincident Neutron	0.3
Pulverized Pellets	NaI	-
	Coincident Neutron	0.8

As one might expect from examination of sodium iodide counting techniques, the data for half and pulverized pellet samples were of questionable value because of density and surface area inconsistencies with solid pellet standard data. Initial data review indicated that gamma counting of the three different physical forms of pellets resulted in three statistically different groups of test results. A similar review of the neutron measurements did not show this variation. A more detailed evaluation of the data was initiated.

During cleanup of a minor alpha contamination spread, four of the samples were inadvertently lost before completion of the analytical chemistry measurements. Four replacement samples were loaded in micro-calorimeter capsules and counted by neutron assay techniques. The measurements, accomplished under General Electric funding, were made to ensure that the experimental design would be as complete as possible. No gamma (NaI) measurements were made on the four replacement samples because the equipment had been returned to Brookhaven National Laboratory.

D. TASK 2A. FABRICATION CAMPAIGN MATERIAL BALANCE - ISE CAMPAIGN 3

One of the objectives of the Integrated Safeguards Experiment was to close measured material balances about three separate fabrication campaigns. The information and experience gained during the two previous campaigns was used to formulate plans for ISE Campaign 3.

Evaluation of all ISE Campaigns 1 and 2 data was not completed in time for use during planning ISE Campaign 3. The incompleteness of data evaluation necessitated the use of some engineering estimates. In addition, delays in the fabrication schedule made it impossible to complete the planned work during Fiscal Year 1971. The scheduling delays, incompletely evaluated data, and uncertainty of funding in Fiscal Year 1972 resulted in suspension of additional efforts on ISE Campaign 3.

E. TASK 2B. COMPUTER INFORMATION

The General Electric funded Mark II Mechanized Accountability and Criticality System was used for the annual Safeguards Inspection of the General Electric Plutonium Laboratory in June. This program replaced the previous Mark I version which did not provide limits of error or complete data files. The Mark II program writes approximately 25 reports using four data files. These files include: (a) batch chemical analysis data, (b) transaction data on material transfers, (c) history file of batches, rods, and (d) the previous ending book inventory. Standard errors (1 sigma) are calculated for individual packages and propagated to include all batches for the laboratory as a whole.

IV. MISCELLANEOUS

A. PAPERS

A joint paper, "Calculated Inventory Differences - a Potential Safeguards and Material Control Technique," was prepared by L. T. Hagie and D. C. Wadekammer (General Electric Company) and W. Marcuse (Brookhaven National Laboratory). The paper was presented at the 12th Annual Meeting of the Institute of Nuclear Materials Management, Palm Beach Shores, Florida.

B. VISITORS

The following is a summary of personnel who visited the General Electric Company Vallecitos Nuclear Center to participate in the Integrated Safeguards Experiment:

1. N. Ovuka, United States Atomic Energy.
2. W. Higinbotham and G. Weinstock, Brookhaven National Laboratory.
3. C. Smith, National Bureau of Standards.
4. R. Sher, Stanford University.
5. R. Borthwick, International Atomic Energy Agency.

C. CONTRIBUTORS

The following personnel contributed to the Integrated Safeguards Experiment during the quarter ending June 1971:

Task 2

D. M. Bishop, L. T. Hagie, H. R. Helmholtz, G. C. Martin, M. N. Robles, J. L. Simpson, and D. C. Wadekamper.

General

B. J. Judson, E. F. Kurtz, W. W. Sabol, and M. L. Thompson

PREVIOUS REPORTS IN THIS SERIES

1. Plant Instrumentation Program First Quarterly Report, April 1970 to June 1970, GEAP-12114-1.
2. Integrated Safeguards Experiment First Quarterly Report, May 1970 to August 1970, GEAP-12114-2.
3. Plant Instrumentation Program Second Quarterly Report, July 1970 to September 1970, GEAP-12114-3.
4. Integrated Safeguards Experiment Second Quarterly Report, September-November 1970, GEAP-12114-4.
5. Plant Instrumentation Program Third Quarterly Report, October-December 1970, GEAP-12114-5.
6. Integrated Safeguards Experiment Third Quarterly Report, December 1970 - March 1971, GEAP-12114-6.

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