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A Conceptual Design for a Receiving Station for the Nondestructive Assay of PuO_2 at the Fuels and Materials Examination Facility

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by

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ABSTRACT

We propose a conceptual design for a receiving station for input accountability measurements on PuO_2 received at the Fuels and Materials Examination Facility at the Hanford Engineering Development Laboratory. Nondestructive assay techniques are proposed, including neutron coincidence counting, calorimetry, and isotopic determination by gamma-ray spectroscopy, in a versatile data acquisition system to perform input accountability measurements with precisions better than 1% at throughputs of up to 2 M.T./yr of PuO_2.

I. INTRODUCTION

This report describes a conceptual design for a nondestructive assay (NDA) system that will provide input accountability measurements for PuO_2 feed material received at the Fuels and Materials Examination Facility (FMEF) being constructed at the Hanford Engineering Development Laboratory (HEDL).

We discuss (a) design guidelines, (b) technique selection, (c) instrument performance characteristics and design characteristics, (d) system integration, (e) mechanical layout, (f) maintenance features, (g) additional development and key interfaces, and (h) cost estimates and design and construction schedules.

We assume that the Safeguards Assay Group at the Los Alamos National Laboratory will actually carry out the detailed design, system integration and testing, and system installation. To that end, we specify makes and models of instruments that would be used. We do not intend to exclude other similar instruments, but these choices reflect our experience, areas of expertise, and the fact that extensive software has already been developed for these instruments.

II. PRINCIPAL DESIGN GUIDELINES

The principal design guidelines listed below govern the purpose of the measurements, the size and contents of the input PuO_2 canister, the required system throughput, and personnel exposure guidelines.

A. Function of Receiving Station

The receiving station is to provide input accountability measurements on bulk PuO_2 feed material received at the FMEF.

B. PuO_2 Canister

The primary containment for the PuO_2 will be a stainless steel canister with internal dimensions of 3-in. diam by about 9 in. high with about 0.125-in.-thick stainless steel walls. These canisters will contain 2000 g of PuO_2 at a density of about 2 g/cm^3. Secondary containment outside the glovebox line will be provided by an outer "French can" or double-door transfer system can. This outer can will mate to a glovebox interface and will provide the means to transfer the inner primary canisters into and out of the receiving station glovebox lines.

C. PuO_2 Characterization and System Throughput

The design guidelines consider requirements that existed during the summer of 1980. More stringent requirements dictated by Secure Automated Fabrication (SAF) requirements are to be considered if they do not severely affect the system design. The characteristics of the input PuO_2 are governed by Standard RDT E 13-1 for ceramic-grade plutonium dioxide. The maximum system throughput is governed by an assumed maximum shipment size, yearly average throughput, and the requirement to complete receiving measurements in 30 calendar days after receipt. These guidelines, as well as those for personnel radiation exposure, are listed in Table I.

III. SELECTION OF TECHNIQUES

In this section we describe the techniques selected for the receiving station. It is beyond the scope of this report to discuss all applicable NDA techniques.

We propose a system of passive assay measurements consisting of neutron coincidence counting, calorimetry, plutonium isotopic determination by gamma-ray spectroscopy, and weighing. These techniques can be combined to perform measurements with precisions and accuracies of better than 1% for total plutonium content.

A. Neutron Coincidence Counting

This technique measures the amount of spontaneously fissioning isotopes in the sample by counting the coincident spontaneous fission neutrons. For

TABLE I

THROUGHPUT, ^{240}Pu, AND RADIATION EXPOSURE DESIGN GUIDELINES

	Basic Requirement	SAF Requirement
Yearly throughput (M.T. PuO_2)	1/3	2
Average daily throughput (No. 2-kg canisters/day)	1	4
Maximum daily throughput (No. 2-kg canisters/day)	4	7
^{240}Pu content	<20 wt%	<26 wt%
Personnel exposure (rem/yr)	<1	<0.5

reactor-grade plutonium, the major source of spontaneous fission neutrons is ^{240}Pu, with small corrections (a few per cent) for contributions from ^{238}Pu and ^{242}Pu. References 1-5 describe this technique. Because this technique measures principally ^{240}Pu, the ^{240}Pu isotopic fraction must be known so that the measurement can be converted to total plutonium. This can be provided by the gamma-ray isotopic measurement or from the shipper value.

The main problem with this technique is that corrections must be made for multiplication of the spontaneous fission neutrons. Similar corrections are needed for the multiplication of neutrons arising from (α,n) reactions on the oxygen in the PuO_2 and other low-Z impurities (beryllium, boron, fluorine, lithium, sodium, magnesium, aluminum, arsenic, silicon, chlorine, and carbon). These effects limit the accuracy of the technique when material with different impurity concentrations is being assayed.

Accurate receiving station measurements should be obtained on different cans of PuO_2 from the same batch of material (same isotopic composition and impurity content). The precision from can to can is limited mainly by counting statistics.

Receiving station conditions are conducive to accurate neutron coincidence measurements. All cans have nominally the same geometry, fill height, PuO_2 mass, and are well characterized for impurities. These factors enable calibration of the system over a narrow range with better performance than that from wide-range calibrations.

B. Plutonium Isotopic Composition by Gamma-Ray Spectroscopy

This technique can provide a completely nondestructive determination of the isotopic composition of an arbitrary plutonium-containing sample. In the receiving station these measurements can be used to provide the ^{240}Pu content for interpretation of neutron coincidence measurements or provide the specific power for interpretation of calorimetry measurement. References 6-14 discuss these types of measurements.

The measurement procedure used (also described in Ref. 14) is adapted from that described in Ref. 6. Isotopic ratios are calculated from the net photopeak areas of neighboring lines in the gamma-ray spectrum of the sample under study. Corrections for detector efficiency, sample self-absorption, and absorber attenuation are made from the same spectrum by constructing a relative efficiency curve from the known photopeak areas and branching ratios from one of the isotopes in the sample. This basic technique is independent of the sample matrix and counting geometry and produces absolute isotopic ratios without using calibration standards. In practice, calibration with known isotopic samples produces somewhat more accurate results. This calibration is specific to a particular detector and electronics system. If these units are not changed, the calibration will be stable for a long period of time and will require only infrequent accuracy checks.

C. Calorimetry

Calorimetry, one of the oldest and most accurate and precise NDA techniques, consists of measuring the total thermal power produced by the sample. This power measurement (watts) is combined with knowledge of the sample's specific power (watts/grams plutonium) to produce a value for the total plutonium content of the sample. The sample's specific power is found from its isotopic composition, including ^{241}Am, and the specific power for each isotope, which is known from fundamental nuclear data. The sample's isotopic composition can be found from mass spectrometry values provided by the shipper or from the values determined nondestructively by the gamma spectrometer system.

References 15-18 discuss the principles and applications of calorimetry. The calorimeters proposed in this conceptual design probably would be manufactured by Mound Facility.

Calorimeters can perform very precise and accurate thermal power measurements (~0.1%), and their calibrations are traceable to the National Bureau of Standards (NBS). Advances in automation and end-point prediction techniques[16-18] have reduced measurement times so that throughput rates are compatible with production facility requirements.

The details of sample packaging have a great influence on the accuracy and speed of operation of a calorimeter. The PuO_2 canisters described in Sec. II.B will be compatible with calorimetry techniques.

D. Mass Determination

The gross weight of each PuO_2 canister will be measured upon introduction to the receiving station gloveboxes and again before the sample is removed from the receiving station gloveboxes. Weighing will be done on commercially available balances interfaced to the system control computer.

E. Measurement Strategies

The combination of neutron coincidence counting, gamma-ray isotopic measurements, and calorimetry techniques enables a versatile approach to measurement strategies that can be tailored to current facility requirements regarding accuracy, precision, throughput, and measurement backlog.

We propose three measurement schemes from which the operator may select the one most appropriate to the current facility situation. These measurement schemes are oriented toward measuring "batches" of PuO_2 where a batch consists of several 2-kg canisters with identical isotopic and impurity concentrations. These strategies are summarized in Table II.

Strategy I. Neutron coincidence count all cans in a batch. Total plutonium is obtained by accepting the shipper ^{240}Pu value. From batch to batch,

TABLE II

RECEIVING STATION MEASUREMENT STRATEGIES

I. Neutron Coincidence Count (all cans)	II. Gamma-Ray Isotopic Calorimetry (1 can) Neutron Coincidence Count (all cans)	III. Gamma-Ray Isotopic Calorimetry (all cans)
1. Accept shipper ^{240}Pu value	1. Gamma-ray isotopic plus calorimetry, total plutonium, 0.5% (1σ), plus plutonium isotopic including americium	1. Independent total plutonium measurement on each 0.6% (1σ)
2. Neutron verification, sample to sample within a batch, 0.5%(1σ) 30-min count time	2. Rapid verification of rest of batch by neutron coincidence count	2. Throughput, 3 cans/day/system
3. Total plutonium, batch to batch, 2% (1σ) affected by impurities	3. Throughput similar to Strategy I	
4. Throughput, 12 cans/8 h		

the accuracy of the total plutonium measurement is limited to about 2% by variations in the impurity concentrations. Within a batch, canisters are verified relative to each other to a precision of about 0.5%, (1σ) in a 30-min count. This measurement provides the greatest throughput of all the strategies. Throughput capabilities exceed those of SAF line requirements.

Note that this strategy does not provide a completely independent measurement. It depends on accepting the shipper's values for the ^{240}Pu fraction (and to a lesser extent the ^{238}Pu and ^{242}Pu fractions). Under many conditions, the shipper's values could confidently be used for the measurements. However, the FMEF operating staff must be aware of the implications of relying only on Strategy I neutron coincidence counting measurements for all input accountability measurements.

Strategy II. Perform a long (overnight) gamma-ray isotopic measurement and a calorimeter measurement on one can from a batch. This allows deduction of the plutonium isotopic and americium concentration of each can in the batch, assuming isotopic homogeneity within a batch. From this measurement and the calorimetry measurement, the total plutonium content of the measured canister is determined with a precision of <0.5% (1σ). Rapid verification of the rest of the batch is obtained by neutron counting all cans and comparing the neutron count of each can to that of the calorimetered working standard for that batch.

Throughput for this method is about the same as Strategy I and should exceed SAF line requirements.

Strategy III. Perform a completely nondestructive independent assay for total plutonium content of each canister by calorimetry and gamma-ray isotopic determination. Throughput is lower with this method because it is controlled by the ~4-h needed to make a reasonable gamma isotopic measurement. Total plutonium content is determined with a precision of <1% (1σ). Two gamma-isotopic systems plus two calorimeters will be able to handle the average daily throughput for SAF requirements. The estimated maximum throughput rate of six canisters per day for two gamma-calorimeter systems falls just short of the maximum daily throughput guideline for the SAF line. We propose that the additional throughput for these overload cases be obtained by switching to Strategy I or II.

IV. PERFORMANCE CHARACTERISTICS

In this section we will list proven performance characteristics for the measurement techniques selected for the FMEF receiving station.

A. Neutron Coincidence Counter

1. Precision. For 30-min counts, the coincidence-counting precision has been ~0.5% (1σ) on 1000-g PuO_2 samples of FFTF oxide (~12% ^{240}Pu). Similar results can be expected for the 2000-g PuO_2 samples in the receiving station.

When converting a coincidence counting rate to grams of plutonium, the precision of the effective ^{240}Pu content must also be considered. If the shipper's value is used and it is a mass spectrometer result, then the effective ^{240}Pu precision may be ~0.2% (1σ), and it will have a negligible effect on the precision of the total plutonium content. If the effective ^{240}Pu precision is taken from a Strategy II (overnight) gamma-ray isotopic measurement, then we expect a precision of ~1.5% (1σ), which will dominate the resulting precision of the total plutonium content.

2. Accuracy. For 1000-g PuO_2 samples of FFTF oxide, the accuracy is ~2% for cans from different batches. It is postulated that different impurity concentrations result in different (α,n) multiplication effects that make the batch-to-batch comparison somewhat poorer than the coincidence-counting statistical precision predicts.

3. Throughput. A throughput of about 12 canisters per 8-h shift is probably reasonable with a 30-min counting time.

B. Plutonium Isotopic Composition by Gamma-Ray Spectroscopy

1. Precision and Accuracy. In Fig. 1, the precision and accuracy of 4-h gamma-ray isotopic measurements on 1000-g samples of FFTF PuO_2 are indicated for the major plutonium isotopes by comparing the gamma spectroscopy results with mass spectrometry. The samples had nominal isotopic compositions of 0.06% ^{238}Pu, 86.6% ^{239}Pu, 11.8% ^{240}Pu, 1.3% ^{241}Pu, and 0.2% ^{242}Pu with 600 ppm ^{241}Am. For ^{238}Pu and ^{241}Am the comparison is not shown because the "standard" values

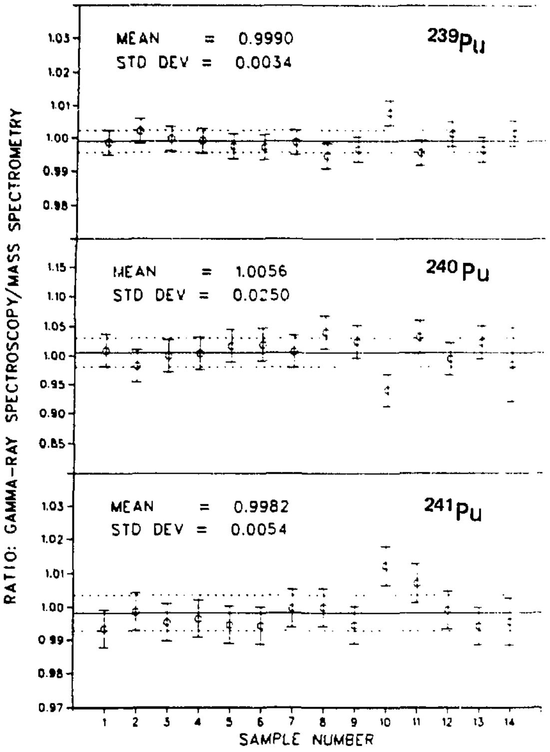

Fig. 1.
Comparison of gamma-ray spectroscopy and mass spectrometry for 4-h measurements of 1000-g PuO_2 samples with ~12% ^{240}Pu.

were not well known. It is difficult to predict these precisions for other isotopic compositions in the range up to 26% ^{240}Pu, but we do not expect them to differ substantially from those shown in Fig. 1.

The indicated precision in Fig. 1 is a combination of that from the gamma isotopic measurements and that from the mass spectrometry values. The mass spectrometry precision is expected to be about 0.04% for ^{239}Pu, 0.25% for ^{240}Pu, and 2.0% for ^{241}Pu, where these values are relative standard deviations. This shows that the mass spectrometry precision contributes negligibly to the observed precision for ^{239}Pu and ^{240}Pu.

The data from samples 1-7 in Fig. 1 are from nominally identical cans from the same batch. For cans 1-7, the deviations represent only those from the gamma spectroscopy measurement. Samples 8-14 represent different batches of plutonium, hence, different mass spectrometry values.

The statistical precision varies approximately as the square root of the counting time. Hence, overnight (16-h) gamma-ray isotopic measurements (Strategy II) are expected to exhibit about a factor of 2 better precision for ^{239}Pu and ^{240}Pu than that shown in Fig. 1.

When these measurements are combined with coincidence counting to produce a total plutonium value, the precision of the ^{240}Pu isotopic measurement dominates the total plutonium precision. When the isotopics are combined with calorimetry to give total plutonium, the precision of the isotopic result for each isotope is weighted with its relative contribution to the sample specific power. In this fashion the effect of the relatively large uncertainty in the

^{240}Pu isotopic measurement is diminished. This will be illustrated in Sec. IV.C.

2. Throughput. Four-hour measurements should allow a throughput of three canisters per day per spectrometer, assuming two canisters per 8-h shift and one canister measured overnight.

C. Calorimetry

1. Precision and Accuracy. The precision of calorimeter power measurements on receiving station canisters should be better than 0.1%. Other uncertainties discussed in Ref. 15-17, such as calibration and nuclear decay parameters, lead to uncertainties of ~0.1 to 0.2% in the absolute power measurement. For the FMEF receiving station, the largest uncertainty in the total plutonium determination by calorimetry and gamma spectroscopy will arise from the uncertainty in the gamma-ray isotopic measurement. A summary of what can be done by this method for 4-h counts on FFTF oxide (~12% ^{240}Pu) coupled with calorimeter measurements is given in Table III and Fig. 2. In Fig. 2 the NDA measurements are compared with destructive chemical analyses.

TABLE III

PRECISION OF DETERMINATION OF SPECIFIC POWER
USING GAMMA-RAY SPECTROSCOPY

FFTF Oxide (Low Americium)	238	239	240	241	242	Americium
Typical isotopic (wt%)	0.061	86.58	11.79	1.35	0.20	595 ppm
Typical isotopic precision 4-h measurement (% rsd)	3.5	0.38	2.8	0.57	--	6.3
Per cent total power	11.7	56.3	28.2	1.5	0.01	2.3

Specific power = 0.00298 W/g plutonium

Predicted precision (1σ) of specific power
(4-h measurement) from counting statistics = 0.9%

Observed precision (1σ) 14 measurements = 0.6%

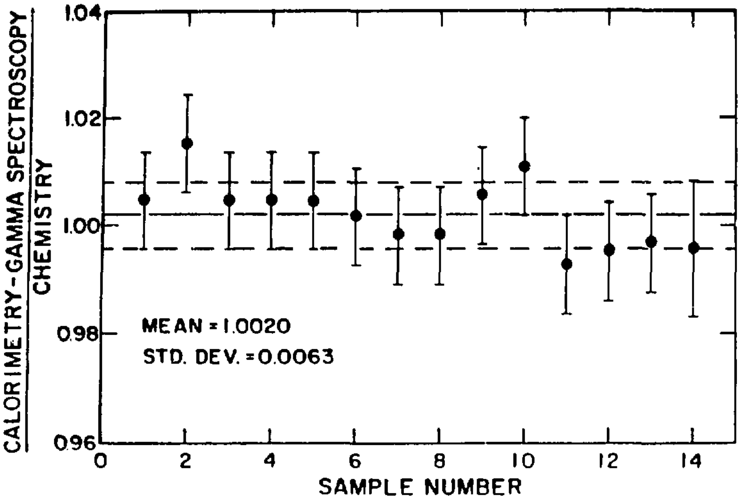

Fig. 2.
Total plutonium determination of 1-kg samples of PuO_2 (12% ^{240}Pu) by combination of gamma-ray isotopic determination (4-h measurement) and calorimeter.

The major cause of the uncertainty of the specific power, and hence the total plutonium content, is the precision of the ^{240}Pu isotopic measurement. For other isotopic mixes with different burnup, higher americium, and higher ^{238}Pu, the ^{240}Pu isotopic precision may be less dominant in determining the specific power.

2. Throughput. A conservative estimate of calorimeter throughput using sample pre-equilibration and servo control is one calibration and two samples per 8-h shift plus a third sample overnight. This makes calorimeter throughput per unit the same as that of the gamma spectrometer.

V. INSTRUMENT DESIGN CHARACTERISTICS

A. Neutron Coincidence Counter

1. Description of Technique. Neutron coincidence counters detect spontaneous fission events in the even isotopes of plutonium. The overall response is proportional to the "effective mass" of ^{240}Pu, which is defined as

$$^{240}\text{Pu eff} = 2.49\ ^{238}\text{Pu} + {}^{240}\text{Pu} + 1.57\ ^{242}\text{Pu}.$$

If the isotopic composition of the plutonium is known, the total mass can be deduced from the coincidence response, which is almost independent of room background and (α,n) reactions within the sample. However, the response is affected by self-multiplication of spontaneous fission and (α,n) neutrons. Assay accuracy is highest when representative standards are available and when the material to be assayed is of uniform well-characterized composition. Both requirements will be met by the FFTF oxide used at the FMEF.

2. Neutron Coincidence Counter Chassis. Figure 3 shows the top of the proposed neutron coincidence counter. The sample container is assumed to be less than 3.5-in. (8.9-cm) diam and 9 to 10 in. (27.9 to 25.4 cm) high, with a 6-in. (15.2-cm)-i.d. in the counter. Between the well and the sample, the stainless steel containment tube is welded to the floor of the glovebox. If the sample diameter exceeds 3.5 in. (8.9 cm), the containment tube diameter and perhaps the neutron counter design must be altered. At present, the containment tube diameter is assumed to be between 4 and 5 in. (10.1 to 12.7 cm). The 6-in. (15.2-cm)-diam well then guarantees that the counter will not touch the containment tube. Also, a 6-in. (15.2-cm)-diam well and a 3.5-in. (8.9-cm) sample diameter will guarantee that the radial efficiency profile across the sample will be flat within 1%.

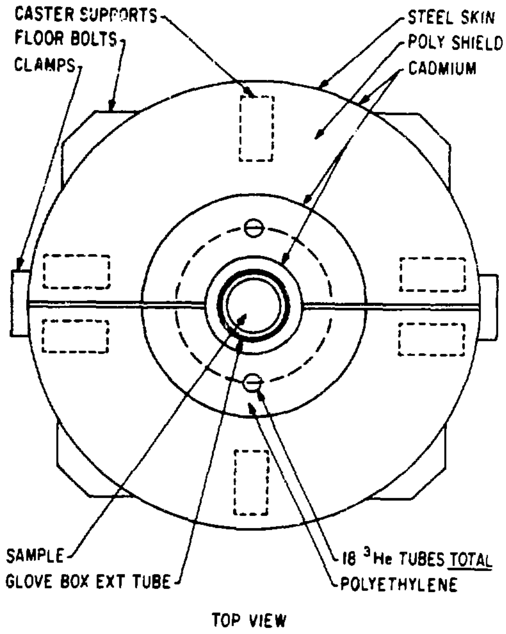

Fig. 3.
Top view of proposed neutron coincidence counter.

Neutrons will be detected by 18 4-atm pressure, 1-in. (2.5-cm)-diam ^{3}He tubes embedded in 4 in. (10.1 cm) of polyethylene. The tubes will be positioned so that the detection efficiency is nearly independent of small amounts of moisture in the sample. The absolute neutron detection efficiency will be about 20%. A 7-in. (17.8-cm)-thick polyethylene shield will surround the neutron counter to reduce the total neutron counting background from other material in the room. This shield will also reduce operator exposure from the sample being assayed. The overall diameter is then 28 in. (71.1 cm). If additional shielding is required in the future, 4-in.-thick portable shields can be placed around the detector without exceeding the 36-in. (91.4-cm) width of the glovebox.

Figure 3 shows the neutron counter as two half-cylinders that can be independently rolled into place and clamped together around the tube extending down from the glovebox. The counter should then be bolted to the floor so that it cannot roll into the containment tube and perhaps breach the glovebox air seal.

Figure 4 is a side view of the neutron counter. The height is 38 in. (96.5 cm), with an additional 4 in. (10.2 cm) of hand-stacked polyethylene shielding. This design is appropriate for gloveboxes at Los Alamos, which are 42 in. (107 cm) above the floor but have angle iron at the sides reaching down to 38.5 in. (97.8 cm) above the floor. If the gloveboxes at HEDL will be a different height, the counter will be redesigned using longer or shorter ^{3}He tubes. Figure 5 shows the estimated axial efficiency profile of the counter, assuming 28-in. (71-cm) active length ^{3}He tubes. If the sample is placed slightly below center as illustrated, the integrated vertical coincidence response across the sample will be constant to within 2%. Also, variations in sample fill height between 6 and 9 in. (15.2 and 22.9 cm) will affect the integrated response by only 0.1%.

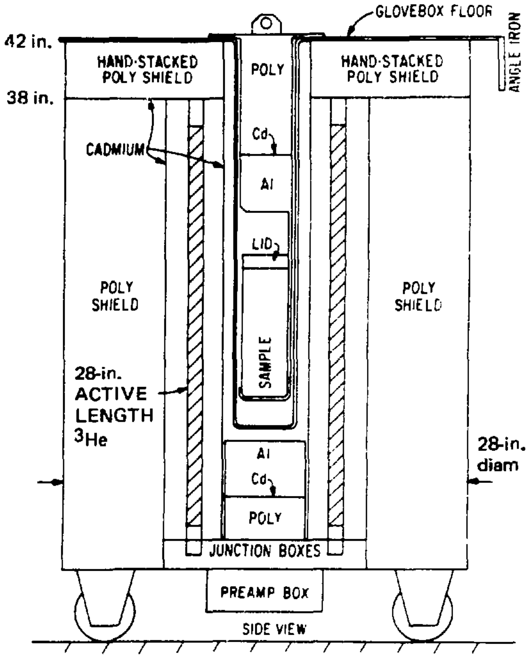

Fig. 4.
Side view of proposed neutron coincidence counter.

As illustrated in Fig. 4, the interior well of the neutron counter

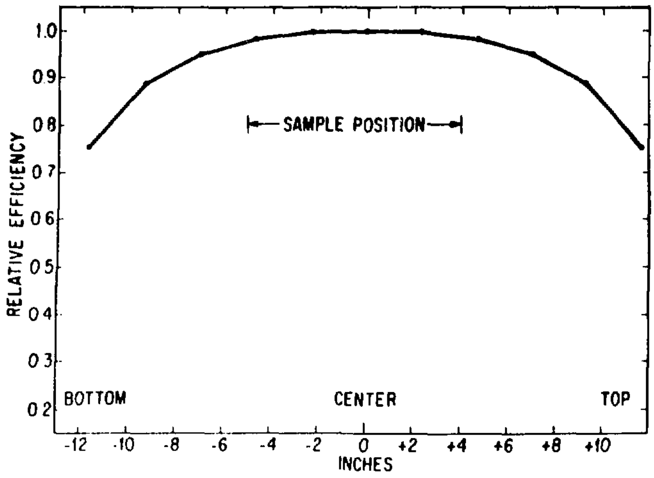

Fig. 5.
Estimated axial efficiency profile of proposed neutron coincidence counter.

contains polyethylene shields and aluminum reflectors. The upper shield and reflector are incorporated in the sample holder, which can accommodate a sample up to 3.5-in. (8.9-cm) diam and 13 in. (33 cm) high, but it cannot handle accidental double batching of two standard FMEF containers. A sample holder similar to that described here is shown in Fig. 6. This holder is in use at the Los Alamos plutonium facility. A Teleflex cable attaches to the sample holder for lifting. A right-angle drive motor (approximately 140 in.-lb of torque) is mounted on top of the glovebox to drive the Teleflex cable, which passes through the top of the glovebox through a rubber seal.

3. Electronics. Because the neutron counter has two halves, two junction boxes are needed at the base of the counter. One six-channel preamplifier box is mounted below the junction boxes. Signals from the preamplifiers are processed by the electronics package illustrated in Fig. 7. This package contains a high-voltage power supply, six amplifiers and discriminators, and a "shift register" coincidence circuit, which records coincident events in a nearly deadtime-free manner.

The electronics package is designed to operate at count rates in excess of 200 000 cps and can accommodate the count rate produced by 2 kg or more of plutonium oxide. The deadtime due to pulse pile-up in the six amplifier channels will be about 2.4 μs.

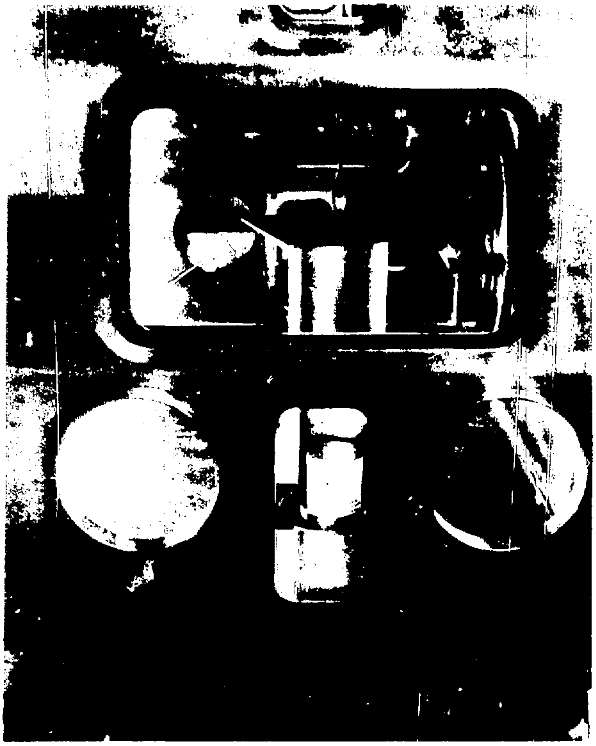

Fig. 6.
Sample holder for a neutron coincidence counter at the Los Alamos Plutonium Facility.

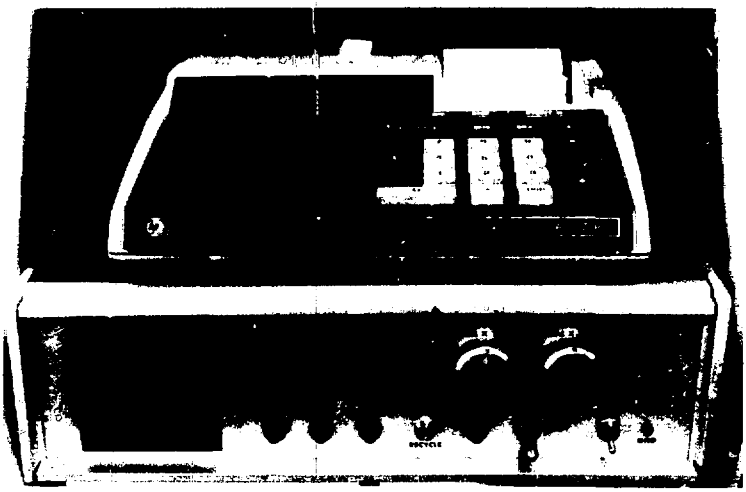

Fig. 7.
Shift-register electronics package for neutron coincidence counting applications.

The electronics package can be mounted underneath one of the gloveboxes near the neutron counter chassis. The electronics can transmit the data collected during the assay to an HP-97 calculator for local readout. The calculator can be programmed to apply count-rate corrections to the data, to calculate the statistical error, and to determine the mass of nuclear material from calibration curves. Also, the electronics package can be interfaced to the receiving station computer so that more detailed data analysis or measurement control functions can be carried out. The microprocessor in the electronics package can operate under computer control.

4. Measurement Control Procedures and Calibration. For neutron coincidence counting, control procedures usually consist of measuring room background and a neutron source or standard sample before every series of sample assays. If room background can vary during the day, it should be checked more frequently. The neutron source or standard should emit coincident neutrons so that all parts of the circuitry will be tested. Neutron coincidence counters using ^{3}He tubes are typically stable to within 0.1 to 0.2%.

For assays of production material, the measured response is corrected for background and amplifier deadtime. Then the effective mass of ^{240}Pu is calculated from a nonlinear calibration curve. This calibration curve should be derived from the assay of a series of known standards similar in size and composition to the production material. From the effective mass of ^{240}Pu, the total plutonium content can then be calculated if the isotopic composition is known from mass spectroscopy or gamma-ray analysis.

The expected assay precision of the neutron counter (due to counting statistics and electronics stability) is 0.3 to 0.4% (1σ) for FFTF oxide samples ranging in size from 100 to 2000 g. The assay accuracy for the ^{240}Pu content of FFTF oxide measured to date is 0.8% (1σ) for samples from a single production batch and 2% (1σ) for samples from different batches. It is believed that these accuracies are limited by self-multiplication of neutrons from (α,n) reactions in impurities. If impurity concentrations at FMEF are lower or more uniform than at Los Alamos, better assay accuracy can be expected. Also, in some cases the assay accuracy can be improved by applying a self-multiplication correction based on the ratio of coincident to total neutrons. Because the proposed detector is well shielded, the total neutron response of the samples should be measurable and may provide useful information.

Determination of the total mass of plutonium is subject to a further (uncorrelated) error arising from the precision of the determination of the isotopic abundance of ^{240}Pu. This error is typically 0.3% (1σ) for mass spectroscopy and typically 2 to 4% (1σ) for gamma-ray analysis. Thus the overall precision of the neutron coincidence counter is expected to vary from about 1% (1σ) for oxide from a single batch with well-known ^{240}Pu content to about 4% (1σ) for oxide from different batches with ^{240}Pu content determined from gamma-ray analyses of each sample.

B. Gamma-Ray Spectrometers

We propose a two-detector gamma-ray spectrometer system that will exceed the basic throughput requirement and nearly meet the peak throughput requirement for the SAF criteria.

1. Detectors. The detectors will be up-looking, planar, high-purity germanium detectors in 30-liter liquid-nitrogen dewars. Crystal size will be ~200 mm^2 by ~10 mm deep. Standard resistive feedback preamplifiers will be specified. Detector resolution should be <500 eV at 122 keV.

2. Mechanical Features. The mechanical features of a gamma-ray isotopic station will be similar to those illustrated in Fig. 8. The shielded planar detector will look upward through a plastic window in the bottom of the glovebox and through a collimating fixture into the bottom of the canister. Movable shields of 0.125-in. (0.32-cm) lead and ~4 in. (10.2 cm) of borated polyethylene provide additional personnel shielding while the sample is being counted. The minimum space envelope needed under the glovebox is about 24 in. (61 cm) wide; with a 30- to 36-in. (76-to 91-cm)-wide envelope more desirable.

3. Electronics. Commercially available nuclear instrumentation module (NIM) standard electronics incorporating pulse pile-up rejection and digital gain and zero stabilization will be used. The electronics for a single detector will be housed in one NIM bin and will consist of (a) high-voltage detector bias supply, (b) linear amplifier with pile-up rejection, (c) scaler operating in recycle mode for count rate monitoring, (d) gain stabilizer, and (e) zero stabilizer.

A rack-mounted oscilloscope can be used to monitor signals from all detectors.

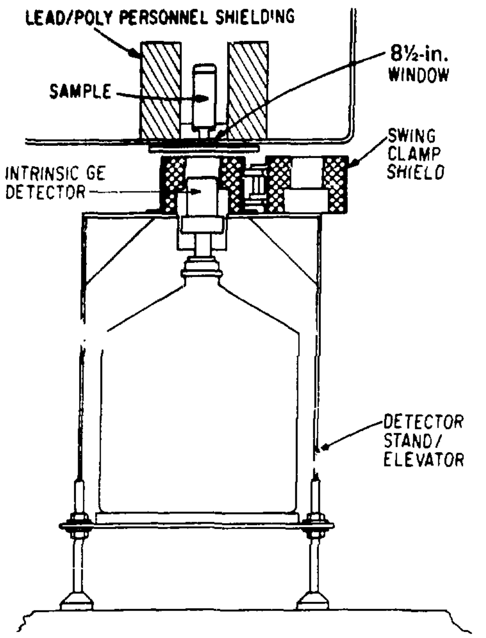

Fig. 8.
Proposed detector station for gamma-ray isotopic measurement.

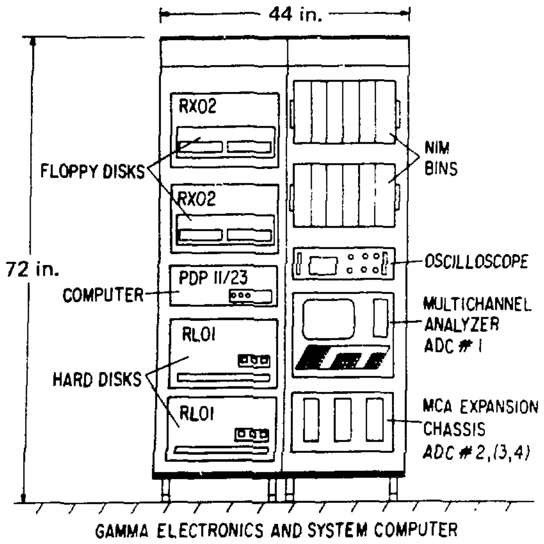

Fig. 9.
Proposed electronics rack layout for gamma-ray spectrometers and system computer.

A computer-based multichannel analyzer (MCA) will collect the pulse-height data from each detector amplifier. The MCA will be capable of accumulating spectral data from as many as four detectors simultaneously. Spectral data will be stored on magnetic disk media. Rack space is sufficient for expansion to four detectors. A concept of the rack layout for the gamma spectrometer electronics is shown in Fig. 9.

4. Data Processing. The gamma-ray pulse-height spectral data will be accumulated in a Canberra Industries model Series 80 MCA interfaced to a PDP-11 series computer. The spectral data are processed by a versatile user-oriented program that reads data from the MCA memory to the computer, computes and prints isotopic results, and stores the spectral data and results on disk. This system can be used as a stand-alone system, independent of central computer control, or it can be operated under control of a system computer.

5. Calibration. The data analysis method[6-14] for gamma-ray isotopic determination of plutonium produces results for isotopic composition that, in principle, are independent of calibration standards. In practice, however, we find that it is

desirable to introduce a calibration constant into the determination of each ratio. These constants correct for incorrect branching ratios, and systematic errors introduced by the specific peak area and relative efficiency determinations used. Typically these adjustments are a few per cent. Because the material for the receiving station is isotopically uniform and reproducibly packaged, the calibration process should produce essentially biasfree results. Calibrations are specific to a particular detector-amplifier-MCA (ADC) combination and may have to be remeasured if any of those components are changed.

C. Calorimeters

1. Operating Modes. Reference 15 provides descriptions of the replacement, differential, and servo-controlled operating modes for the two twin calorimeters proposed here. In the servo-control method, recommended for the most rapid measurements, temperature of the calorimeter chamber is held constant above that of the environment by means of a servo-control mechanism. This temperature difference is maintained by a constant power applied to the heaters in the calorimeter sample chamber. When an unknown is placed in the calorimeter, the power needed to maintain this constant temperature drops, and the difference between the original power and the new power is the power produced by the sample.

2. Pre-Equilibration Bath. To make the best use of the servo-control method, the sample temperature should be the same as the calorimeter chamber temperature when the sample is put into the calorimeter. This is attained by placing the sample in a pre-equilibration bath before it is measured in the calorimeter.

3. Environmental Bath. The calorimeters proposed for the FMEF receiving station will have external-temperature-controlled baths with water circulating through a jacket surrounding the calorimeter and its reference chamber. The calorimeter chamber will be positioned above a similar reference chamber inside a single jacket. Total diameter of a single calorimeter unit will probably be less than 12 in. Calorimeter height is not known, but the unit may require a raised floor in the glovebox or a well in the floor, or it may project into the glovebox. Details of the calorimeter-glovebox interface will be addressed by

Los Alamos, Mound, and the glovebox designers during the detailed design phase of the program.

4. Electronics. Calorimeter electronics will be housed in one rack and controlled by its own computer, which can control as many as eight units simultaneously. Mound Facility is in the process of standardizing their electronics, which will improve maintenance and spare board availability. Computer control is now provided by a PDP-11/03, which will interface easily to the other PDP-11 series computers in the system. The calorimeter computer is controlled by a Mound Facility-designed operating system. This operating system will have to be modified to enable communication with the system control computer. This type of requirement is already being implemented by Mound and should be "on the shelf" by the time the FMEF receiving station calorimeters are ordered.

5. Calibration. Calibration of a calorimeter is necessary in order to derive the sample power from the observed calorimeter output. Two types of calibrations are common. The first is an electrical calibration involving standard resistors and standard voltages traceable to the NBS. The second calibration method uses a standard radioactive heat source (usually ^{238}Pu) whose measured power output can be traced to the NBS. These heat sources may be packaged in a container filled with U_3O_8 to completely mock up the sample geometry that is used in the calorimeter. Calibration methods are more fully discussed in Ref. 15.

D. Balances

Canisters will be weighed when they are put into the verification station glovebox system and again upon removal from the system. Electronic balances with a 15-kg capacity and 0.1-g sensitivity will be provided at the input unloading station and also next to the neutron coincidence counter. A balance next to the coincidence counter is provided to improve material handling because the coincidence counter is expected to have the greatest throughput of all the NDA instruments. Canisters can be removed from the vicinity of the neutron coincidence counter without having to transfer them back to the input glovebox. These balances will have the capability of being read by the system control computer.

We do not specify models in this conceptual design. We plan to incorporate the type of balance chosen by HEDL for other stations at the FMEF to improve compatibility and enhance maintenance opportunities. Our ground rule for incorporation of HEDL-selected balances is that they be able to communicate with a standard Digital Equipment Corporation (DEC) serial line interface.

E. Identification (ID) Readers

As with the balances, we do not specify an ID reader but will incorporate the model chosen by HEDL for the rest of the facility. Communication to the system computer through a standard DEC serial line interface is a requirement.

F. Hand-Held Terminals

We propose to incorporate hand-held terminals at the gloveboxes where the PuO_2 is introduced or removed from the glovebox line. These terminals, wired in parallel with the system terminal, will be used to instruct the computer to read the sample ID and weight. This means that the operator will not have to run back and forth to the system terminal to execute these functions.

VI. SYSTEM INTEGRATION

A. System Communications

A block diagram of the system interconnections is shown in Fig. 10. The heart of the system is a Canberra Series 80 MCA-Jupiter computer system. In addition to controlling the Series 80 MCA and analyzing the gamma spectroscopy data, the Jupiter's PDP-11/23 computer will also service the neutron coincidence counter and the calorimeter systems.

Because servicing three assay instruments is not time critical, a single-user RT-11 operating system will be used. The computer will continually poll the instruments to see if their acquisition cycle has completed. When an instrument completes its data acquisition cycle, the necessary analysis will be performed and results will be stored on local mass storage devices and also transmitted to the central accounting computer, if necessary. This should require, at most, 1 to 2 min for the gamma-ray isotopic system, which has the most extensive data analysis requirements.

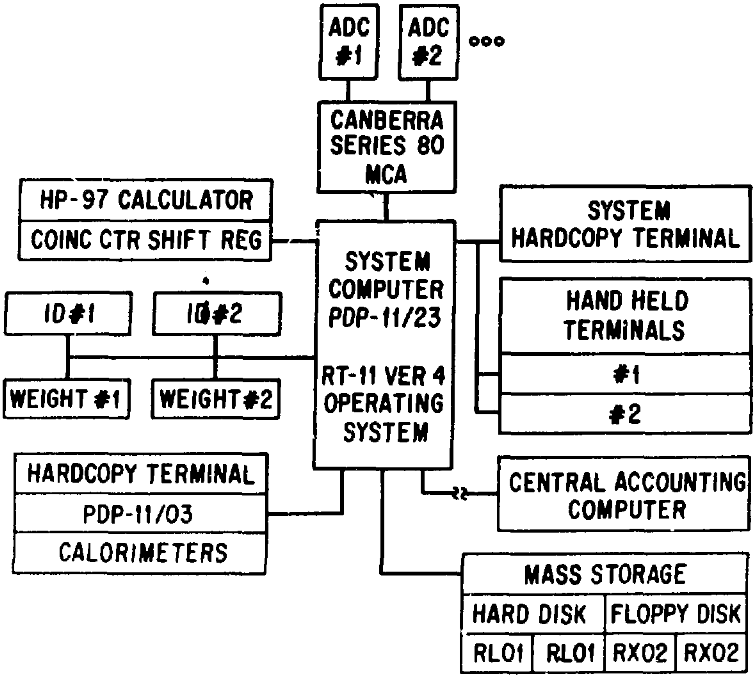

Fig. 10.
Receiving station system block diagram.

B. System Redundancy

Several features are incorporated into the system to enable assays or verifications to continue, even if some instruments are down for maintenance. Failures of single blocks in the system are handled by the combination of redundant hardware and redundant analysis techniques. The calorimeter and the neutron coincidence counter are designed to operate independently in a stand-alone mode if the system computer is down. The calorimeter can output its results to its own hardcopy terminal under control of its dedicated computer. Likewise, the neutron coincidence counter can output its results on its Hewlett-Packard Model 97 calculator printer. Assays can continue after failure of a single calorimeter or a single gamma spectrometer by using the second system present in each method. If the Series 80 MCA goes down, calorimetry and coincidence counting can continue. Back-ups are provided for both types of mass storage devices. The hardcopy terminal on the PDP-11/03 with the calorimeter system provides back-up for the hardcopy terminal on the system computer. An outline of these redundancy features is given in Table IV.

TABLE IV

SYSTEM REDUNDANCY

Hardware Component	Action Upon Failure
System computer	1. Stand-alone neutron counter 2. Stand-alone calorimeter 3. Strategy I analysis 4. Strategy II or III using shipper isotopic value 5. Manual data transmission to central accounting computer
System hardcopy terminal	1. Replace with terminal from calorimeter system
Mass storage devices	1. Use back-up
Series 80 MCA	1. Strategy I analysis using neutron counter 2. Calorimeter still operational, use shipper isotopic value for Strategy III
Gamma detector or its electronics	1. Use second system
Calorimeter or its electronics	1. Use second system
Calorimeter computer	1. Use neutron counter and Strategy I
Calorimeter hardcopy terminal	1. Used only for stand-alone operation
Coincidence counter	1. Use calorimeter and gamma-ray isotopic value, Strategy III
ID readers, balances, hand-held terminals	1. Use second system 2. Use system terminal as back-up for hand-held terminal

C. Software Features

Although specific software features cannot be described yet, the overwhelming majority of the software effort will be directed toward control and communications. The data analysis is well understood and will be a minor part of the total software effort.

Final and intermediate measurement results (perhaps 50 numbers per sample) will be stored on local mass-storage media for use by the receiving station operators. This will not be a large data base management operation and the central accounting computer will not have access to these data files. Programs to access these data files will be run off line as required by the receiving station operations. Only the few measurement results required by the central accounting computer will be transmitted to that unit.

The software will incorporate a measurement control program. Details can be discussed between HEDL and Los Alamos during system design. We favor a program that provides warnings of out-of-control operation as opposed to one that prohibits all measurements if out-of-control operation is detected. The frequency of measurement control runs would probably be (1) neutron coincidence counter, daily, (2) calorimeter, daily to every third day, and (3) gamma-ray isotopic system, weekly or less frequently.

VII. MECHANICAL LAYOUT

A. Floor Plan

A suggested floor plan for the receiving station is given in Fig. 11.

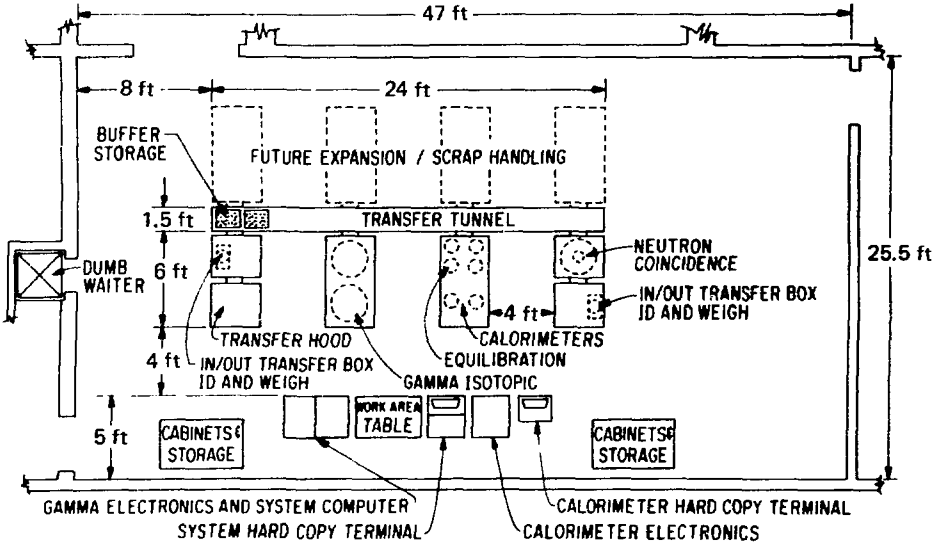

Fig. 11.
Suggested floor plan for FMEF receiving station.

B. Features

1. Neutron counter removed from buffer storage area to minimize backgrounds.
2. Measurement boxes attached to a transfer tunnel to minimize interference to in-progress measurements during sample changing and unloading.
3. Calorimeter pre-equilibration bath adjacent to calorimeters for rapid transfer from pre-equilibration to calorimeter measurement.
4. Movement of samples in transfer tunnel by a trolley or pulley arrangement to minimize handling.
5. Access to both sides of NDA instruments under gloveboxes for easier maintenance.
6. Shadow shields inside gamma-ray isotopic gloveboxes to reduce personnel exposure during sample count time.
7. Rolling, movable neutron and gamma shielding around calorimeter and pre-equilibration bath.
8. Shielded buffer storage racks.
9. Lead-sandwich glovebox construction.
10. Gloveboxes with provision for addition of 4 to 6 in. of hydrogenous neutron shielding.
11. Second input-output station near neutron coincidence counter for improved sample handling.
12. Expansion capability for future expansion or scrap-handling capability.
13. Possible use of hand-held terminals at weighing stations.
14. Modular design to enable replacement of individual gloveboxes if program requires.
15. Two IN/OUT transfer stations to handle French cans and/or shipping cask as needed. (We suggest that I/O to gloveboxes be done from and to the vault with canister in a French can. Shipping cask should be unloaded to the vault in another area.)

C. Implementation

The glovebox hardware will not be designed and/or implemented by the Los Alamos Safeguards Assay Group; therefore, the cost and schedule for the glovebox detail design will not be addressed in the cost and design schedules that follow.

As much as possible, the gloveboxes with the important design features suggested above should be compatible with others in the FMEF facility. Hardware design details should be discussed with the operating personnel who will use the system.

The arrangement of the glovebox line within the room may have to be reconsidered after the scrap-handling-line requirements have been defined. Cross-contamination considerations may dictate a scrap line entirely separate from the receiving station.

D. Electrical Service

The following gloveboxes require 110-Vac electrical service:

(a) input and output boxes for balances and ID readers,

(b) outside neutron coincidence counter box for motor to raise and lower well plug, and

(c) outside calorimeter and equilibration bath boxes for motors to raise and lower well plugs. (This could be done manually.)

Electrical power can be standard "house power" for the gloveboxes and the instrument racks.

VIII. MAINTENANCE FEATURES

Wherever possible the design of the FMEF receiving station will incorporate commercially available equipment to facilitate maintenance. Below we suggest sources of maintenance to supplement HEDL's own in-house capability.

A. Neutron Coincidence Counter

1. Helium Tubes. Failure unlikely. Single tube failure will not significantly affect performance. Matched replacement tubes available from vendor.

2. Shift Register Coincidence Electronics. Commercially available from IRT Corporation. Local on-site maintenance by skilled HEDL technician using IRT manual. Consult with users of other units in Hanford complex at Rockwell and Battelle. Capabilities of IRT factory maintenance unknown.

3. Hewlett Packard Calculator. HP-97 maintenance by manufacturer.

B. Calorimeter

1. Servo-Control Electronics. Composed of commercially available units. Maintenance by factory service, consultation with manufacturer, and Mound Facility.

2. Calorimeter Interface Cards. Custom Mound Facility design standardized for easier maintenance. Maintenance by replacement with spare boards supplied by Mound.

3. Computer and Peripherals. Standard DEC components, maintenance by DEC or HEDL.

4. Calorimeter Systems Back-up. Two calorimeter systems provide back-up.

C. Gamma-Ray Spectrometer

1. Back-up Capability. Two detectors and associated electronics provide back-up.

2. Germanium Detectors. Repair by vendor at factory. Detectors require liquid nitrogen cooling at all times high-voltage bias is turned on. Estimated consumption is 10 liters/week/detector.

3. Germanium Detector Signal Processing Electronics. Commercially available NIM modules; repair locally or at factory.

4. Canberra Series 80 MCA. Maintenance by local factory-trained HEDL technician by consultation with factory. Maintenance by Canberra Field Service engineer.

D. System Computer

Maintenance will be performed by DEC or HEDL. DEC may not service this unit because it will be packaged in a non-DEC chassis. This is necessary because the standard DEC chassis for the PDP-11/23 does not provide enough card space for the system's requirements. One advantage to the non-DEC chassis is much easier access for maintenance. We feel this advantage outweighs the possibility of using a DEC expansion chassis.

The system computer peripherals (terminal and mass storage) will be standard DEC components; maintenance by DEC and/or HEDL.

E. Balances and ID Readers

These units will be identical to other units in use at the FMEF. The same maintenance support will be used as for the other FMEF units.

F. Hand-Held Terminals

Commercially available units, factory and/or HEDL maintenance.

During the course of the system detail design we reserve the right to select components other than those mentioned above if a performance or maintenance advantage will be gained.

IX. KEY INTERFACES

Some areas not addressed in this conceptual design must be identified so that communication can be initiated between the NDA designers and other personnel involved in the FMEF project.

A. Glovebox Design

Detailed glovebox design will not be considered by Los Alamos in the follow-on design phase of this program. Liaison between the NDA designers and others must be established to ensure that (1) adequate space envelopes are provided, (2) sufficient electrical service is present, (3) glovebox wells and windows are properly provided, and (4) cable runs are provided to electronic racks. Other considerations will arise as design proceeds.

B. ID Readers

Los Alamos has not considered the details of interfacing specific balances and/or ID readers into this conceptual design. We plan to incorporate the standard units that will be used elsewhere in the FMEF facility. When these are established, the information must be transmitted to Los Alamos for incorporation into the detail design phase of the project. To complete the cost estimates in Sec. XI, we priced specific models that we believe would work; however, unless problems arise, we will attempt to incorporate standard units selected by HEDL for use throughout the FMEF. HEDL's selection of balances and ID readers must be sent to Los Alamos within 2 months of the start of the design contract so that we can begin procurement and study the interface requirements.

C. Criticality Safety

Criticality safety analysis of the receiving station conceptual design should be provided by the HEDL operating personnel who will be responsible for criticality safety in the FMEF facility. This investigation should include the implications of the water baths and flowing water loops in the calorimeter systems.

D. Mound Facility

The calorimeters will be provided by Mound Facility in consultation with Los Alamos. The interface between the Mound calorimeter computer system and the receiving station control computer must be defined because the Mound calorimeter control system uses a Mound Facility custom-designed operating system. This interface will be defined by Los Alamos and Mound and will be fully tested during system integration.

In addition, early in the detailed design phase, we must obtain firm dimensional information on the calorimeters and equilibration baths for use in the design and fabrication of the glovebox system.

E. Quality Assurance

Quality assurance functions will be supplied by HEDL. All Los Alamos design work will be in accordance with good engineering practice. However, it will be HEDL's responsibility to assure that all equipment complies with their quality assurance requirements. HEDL will initiate this liaison with Los Alamos.

X. ADDITIONAL DEVELOPMENT

Section IV discussed the performance characteristics of the three NDA instruments proposed for the FMEF receiving station. These performance characteristics are proven numbers and not extreme extrapolations. There is essentially no additional development needed to attain these performance characteristics.

Continuing research and development at Los Alamos could lead to improvement in the performance of the NDA instrumentation. Two areas where improvements could be made are (1) multiplication corrections affected by (α,n) neutrons from impurities, and (2) better precision on ^{240}Pu isotopic measurements from gamma-ray spectroscopy.

During the detailed design and implementation phase of this project, we will incorporate the best methods available for the measurement analysis.

XI. COST ESTIMATES

A. Hardware Procurement

1. Gamma-ray isotopic system (two spectrometers) and main computer	
a. Multichannel analyzer, MCA expansion chassis, ADCs interfaces, computer, computer peripherals	\$ 60 000
b. Software licenses	3 700
c. Intrinsic germanium detectors (2)	18 000
d. NIM electronics	12 500
e. Oscilloscope	1 500
	\$ 95 700
2. Calorimeters (2)	\$150 000
3. Neutron coincidence counter (commercial hardware only)	29 100
4. Balances with remote electronics (2)	17 700
5. ID readers (5)	12 500
6. Hand-held terminals (2)	5 200
Hardware procurement total:	\$310 200

B. Los Alamos Design and Fabrication

1. Gamma-ray isotopic	
a. Detector stands and shields	$ 8 000
b. Sample shadow shields	2 000
2. Calorimeter	
a. Stands for calorimeter and equilibration baths	2 000
b. Roll-around shielding for calorimeters and equilibration baths	5 000
3. Neutron coincidence counter	
a. Detector assembly, moderator, shielding	12 000
b. Stand to bolt to floor	1 000
c. Electronics rack under glovebox	1 000
d. Motor drive for sample well	2 000
4. Balances, ID readers, hand-held terminals	
Mounting fixtures for gloveboxes	4 000
5. Cabling for all systems	2 000
Los Alamos design and fabrication total:	$ 39 000

C. Los Alamos Personnel

Task	FTE Months	Calendar Months
Procurement	3	3
Measurement design	6	4
Software development	13	
Initial		6
Revisions		2
System integration	6	3
System testing	8	3
Liaison	9	ongoing
Shipping		
Direct cost	($4K)	
Preparation	1	1
Training	0.5	0.25
Installation	6	1
Documentation	9	6
	61.5	

Los Alamos personnel total 61.5 full-time equivalent (FTE) at $7 000/FTE-month, which includes salaries, fringe benefits, materials and supplies, and laboratory overhead.

	$430 500	
	+ 4 000	(shipping)
Total cost:	$434 500	

D. Cost Summary

Capital equipment procurement	$310 200
Mechanical design and fabrication	39 000
Personnel	434 500
	783 700
Contingency at 15%	+ 117 500
System cost, 1981 dollars	$901 200

Allow inflation at 12% per year from January 1981 to start of contract. Allow for inflation at 12% per year for personnel costs in second year of program, assuming personnel costs evenly split over 2 years—approximately $25 000.

XII. POTENTIAL COST SAVINGS

This conceptual design is proposed to conform to specific requirements presented by HEDL in their request for the design. Several areas present possibilities for reductions in the cost of the receiving station system. These cost reduction areas violate the original ground rules for the conceptual design but may be seriously considered as requirements change.

A. Hardware

Hardware reductions result in relatively small savings. One gamma-ray spectrometer and one calorimeter system can be deleted. The savings of about $23 000 for the gamma spectrometer and about $40 000 for the calorimeter will result in loss of system performance: (a) the redundancy and back-up capability (Secs. VI.B and VIII.B and C) of two systems, and (b) the ability to handle nearly any peak load condition with Strategy III measurements. The Strategy III throughput will drop to three canisters/8-h day.

Reductions in the mass storage capability can be achieved by deleting one or two disk units at a savings of $4000-8000. The back-up feature of a second disk unit will be lost.

B. System Integration

Significant cost reductions can be achieved if HEDL will accept independent assay instruments that are not integrated into a unified NDA system. This would mean a loss of computer control for system measurements. Measurement ults from individual instruments would be combined manually to give total plutonium content. Although these calculations are simple, errors will be introduced by transposed numbers, improperly read sample IDs, and similar areas where human factors enter.

System integration at a later date will present unique difficulties. Because the instruments will be in routine use, measurements will have to be stopped for testing periods. Los Alamos will not have an identical system to work with to develop an integrated system.

If independent instruments are purchased initially, HEDL will probably integrate the system. In that case, HEDL should be assured that the individual instruments purchased would be compatible when integrated.

The initial cost savings of this option would be significant. Reductions in personnel costs would occur in the areas of measurement design, software development, system integration, system testing, and documentation. These savings could total at least $150 000; however, the cost of later system integration would probably exceed the initial savings.

C. Gloveboxes

The conceptual design presented here assumes that PuO_2 singly contained in an inner canister is transferred from a shipping container into a glovebox. This approach is undesirable because the exterior of the canister is potentially contaminated, which means that the shipping container can also become contaminated.

Shipping the PuO_2 in double containment is the accepted practice. If we assume that this double containment is an inner canister with an outer French can, then this package can be used with any of the NDA instruments without introduction into a glovebox.

Deleting gloveboxes from the design will reduce overall receiving station costs. Although the specific glovebox costs have not been addressed in this conceptual design, we estimate that the glovebox system discussed in Sec. VII would cost about $200 000 for hardware, accessories, and installation. Also, if gloveboxes are deleted, mixed-oxide scrap and waste could be assayed if it were packaged like the incoming PuO_2. This could save an additional $100 000-200 000 by deleting scrap-handling gloveboxes. Material handling would also be improved if all assay instruments were outside gloveboxes.

If gloveboxes are deleted, the sizes (and cost) of the neutron coincidence counter and the calorimeters would be increased to accommodate the double containment required for the plutonium samples. (Also, the speed of calorimetry might be reduced.) However, these cost increases would be offset by deleting the requirement for glovebox interfaces for the NDA instruments.

Canisters and French cans for NDA applications should be designed so that container sizes, especially flange diameters, are reduced, wall thicknesses are minimized, and air gaps between the inner and outer canisters are reduced.

XIII. PROGRAM SCHEDULE

Assuming that the system will be designed, fabricated, assembled, and tested at Los Alamos, we propose the schedule shown in Table V. Delivery of the system will be 2 years after the initiation of the program.

TABLE V

HEDL RECEIVING STATION PROJECT

Time After Start of Contract

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
PROCUREMENT	■	■					■																							
MEASUREMENT DESIGN			■	■	■	■																								
MECHANICAL DESIGN							■	■																						
FABRICATION									■	■																				
CALORIMETER MANUFACTURE				■	■	■	■	■	■	■	■	■	■	■	■															
SOFTWARE DEVELOPMENT								■	■	■	■	■	■						■	■										
SYSTEM INTEGRATION															■	■	■													
SYSTEM TESTING																		■	■	■	■									
DOCUMENTATION																	■	■	■			■	■	■						
TRAINING																						■								
SHIPPING																							■							
INSTALLATION																								■						
LIAISON	-	-	-	-	-	-	ongoing	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-						

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