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MATERIALS CONTROL IN THE FABRICATION OF ENRICHED URANIUM FUELS*

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ABSTRACT

Intense activity in the field of fuel element technology at Oak Ridge National Laboratory during the past 15 years has lead to the establishment of sound process and enriched material control procedures that find wide applicability in the commercial fabrication of fuel elements today. Reliable techniques for handling enriched fuel in alloy, dispersion, and bulk oxide form were developed and adopted as standards in the course of design and fabrication of prototypic fuel elements for startup operation of the Materials Test Reactor, Bulk Shielding or "Swimming Pool" Reactor, Army Package Power Reactor, Tower Shielding Reactor, Geneva Conference Display Reactor, High Flux Isotope Reactor, and the Experimental Gas-Cooled Reactor. The experience gained

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serves as background for this paper, which will stress material control problems and their solution during the fabrication of various types of enriched uranium fuel components.

The basic objectives to be met in the design of a good materials control system are: (1) minimizing the number of material units to be accounted for, (2) designing separate records for each major fabrication step and linking these in a manner that permits isolation of differences with a minimum of effort, (3) integrating the maximum number of controls into the minimum number of records to eliminate duplication, and (4) introducing a sufficient number of cross-checks into the system to ensure reliability. In every fabrication program, successful control was achieved by establishing a unit procedure in the following areas: (1) beginning materials in the as-received form, (2) fabrication of components, (3) component processing, and (4) scrap handling. Consolidation of control records into a master summary was helpful in confirming the materials inventory, evaluating the fabrication process, and preparing management reports.

Establishment of sampling methods and examination of results indicated that multiple control is necessary to ensure proper fuel content. Mechanical adjustment and density measurement were successfully used where alloy fuel content was critical. Scrap handling had an important effect on the materials balance, by which fuel content was confirmed and good accountability was assured. Records and handling procedures, including batching and physical marking methods, were formulated in a manner that assisted the fabricator in criticality control.

INTRODUCTION

The scarcity, expense, and hazards of nuclear materials have often been cited as reasons for their need of proper control and management. Equally important, however, is that technical success in the manufacture of fuel elements, particularly those containing enriched uranium, depends largely upon how well these controls are fitted to each operation.

My purpose is to discuss the major control problems in the fabrication of enriched uranium fuels and their solution. The material presented is based on successful controls applied during the fabrication of a

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variety of fuel elements at the Oak Ridge National Laboratory, from the receipt and verification of starting materials to the process control summary performed upon completion of the fabrication effort.

Special problems in the handling of nuclear material, as opposed to conventional material, will be considered before the basic objectives in systems design are stated. After a brief description of fabricated product types, thorough discussion of enriched-uranium control procedures applicable to a general fabrication effort will be presented.

SPECIAL CONSIDERATIONS

Since enriched fuel element fabrication utilizes standard metallurgical processes and equipment, the process controls are similar to those found in any metals or ceramics industry. There are end product specifications regarding chemical makeup, dimensions, and strength and process concerns such as weld integrity and grain size. These and other factors must be controlled within close tolerances.

In the area of materials control, however, there are few similarities between conventional and nuclear operations. Enriched uranium presents unique control problems in handling and processing. In addition to the regular health and safety hazards, the enriched-uranium fabricator handles a material that can, if not properly controlled, seriously damage his personnel and equipment. If the uranium is highly enriched, he also risks loss of a very expensive material.

Health Hazards

During enrichment of ^{235}U by the gaseous diffusion process, the very active ^{234}U is also enriched. Although external damage to the human body resulting from this alpha activity is minimal, when this material is ingested or inhaled, the hazard becomes acute. Therefore, we need to prevent it from entering the body.

Criticality Control

The extreme property damage and loss of life that could result from a critical accumulation of ^{235}U in the fabrication process area demand

strong measures to ensure nuclear safety. Geometric control provides the best means of preventing a critical incident, but it must be reduced to practical terms and limits understood by the process technician. In addition, administrative practices must provide for a continuous surveillance to make certain that these limits are being adhered to. Yet, the limits must be flexible enough to permit some alteration for changes that occur in the process. Therefore the criticality expert should evaluate both the equipment and the process in setting limits.

In-Process Losses

The value of highly enriched uranium requires that careful attention be given to the smallest chances for losses, unnecessary accumulations of in-process materials, and the possibility of mixing with materials of lower enrichment. The design of process methods and equipment is very important in this respect.

Such procedures as filtering and sampling all exhausts, glove-box containment of powdered materials, and periodic burn recovery of filters should be established. There should be no open drains in the primary fabrication area, in which the uranium is first incorporated in non-fissile materials, and all spills should be cleaned up with dry, absorbent materials that can be burned for recovery.

The measurement methods, including weighing, sampling, and analysis, must be of the highest quality. The accumulation of small but regular systematic errors in measurement can falsely indicate a loss of many dollars or, more seriously, obscure actual losses.

The general problem of the nuclear materials manager, therefore, is complex and must be solved largely by coordination. He must design a system that will not interfere with the process objectives, yet will ensure safe handling and protection of the materials. In addition, his system must generate sufficient data to ensure product quality, statistically evaluate the process, and enable the necessary management reports.

BASIC OBJECTIVES

The basic objectives of a good materials control system are:

(1) minimizing the number of material units to be accounted for, (2) establishing separate records for each major fabrication step and linking these in a manner that permits isolation of differences with a minimum of effort, (3) integrating the maximum number of controls into the minimum number of records to eliminate duplication, and (4) including a sufficient number of cross checks to ensure reliability.

Material Units

All quantity controls of enriched uranium are in terms of grams. Accounting for the materials in process is simplified, however, if the control basis is changed to a piece count of components of known uranium mass as they are fabricated. For example, when 400 g ^{235}U is fully contained in 20 identified fuel plates, the control should be by plate rather than gram. Furthermore, when these 20 plates are brazed into a single fuel element, the control should shift to the element. In general, then, the number of units should be progressively reduced as the materials flow through the process.

Records

Enriched fuel materials are controlled for two purposes by a complete record around each major fabrication step. First, the fabricator can balance the quantity of uranium fuel in the starting materials of each step against the quantity in its end products to confirm the intended fuel content, evaluate any process losses, and limit the size of the process area and the number of records that must be examined should any unusual differences occur. Second, use of the final balance of each step as the initial balance of the next step in the process links all data into a complete materials control history for the entire process and provides the basis for all evaluation of product fuel content and reporting for accountability.

As previously stated the fuel manufacturer must control other general specifications of the fabricated pieces as well as the fuel

content within close tolerances. Methods for meeting such specifications include mechanical and chemical measurements and statistical evaluation of variances.

Integration of Controls

The records needed for each fabrication step should integrate both the general and fuel-control information into a dual-purpose form, thus reducing the number of forms needed and eliminating duplications. In addition one can detect important relationships between fuel-content data and process data that might otherwise go unobserved.

Cross Checks

The danger of dependence on a single measurement of fuel content during any stage of the fabrication process becomes apparent when one considers the accidental variations that can occur. Balances can be off calibration, chemical analyses can be incorrect or improperly stated, and human error is always possible. To save time and expense, however, the fabricator must minimize the number of measurements and ensure himself against intolerable fuel-content deviations with sufficient reliable cross checks. These fall into four categories.

Method and Equipment Checks. - At the Oak Ridge National Laboratory, all balances for weighing fertile and fissile material are regularly calibrated against precise standards. Each calibration is recorded on a chart kept at the balance, and significant deviations dictate equipment removal for repair or replacement.

Random and Backup Sampling. - The fuel content of the fabricated component may also be confirmed by chemical analysis of random components. Because the component is destroyed, this type of sampling should be limited to the minimum number of samples from which a sound statistical evaluation can be made, and the components should be removed at the earliest possible stage of their processing.

During regular process sampling, an extra backup sample should be taken and held for a repeat measurement should later data fail to correlate with the original results.

Statistical Evaluation. - Trends that are apparent in a regular review of all process data will often indicate control problems that are not obvious in the day-to-day data accumulations. In one evaluation of the difference between intended and chemically analyzed content of uranium-aluminum alloy over a rather long period, we noted that new heats that included remelted aluminum-clad uranium-aluminum alloy plates usually had a higher uranium-to-aluminum ratio than intended. Investigation showed that the outer cladding material of the plates, which was of different composition than the high-purity fuel diluent material, contained small amounts of copper that were titrated with the uranium during the analytical procedure. Including an analysis for copper and adjusting the uranium analysis for the copper content corrected the situation.

The Material Balance. - One of the most important methods of cross checking the routine process controls is the material balance. A complete and thorough materials inventory is correlated with the accounting book balance at the end of a selected period. We shall discuss this in detail later.

FABRICATED PRODUCTS

The types of enriched uranium fuel elements are almost as numerous and varied as the reactors now in existence. Indeed, one often has more than one specification for elements in the same reactor system. We shall, however, consider three general categories classified according to the physical form of fuel and illustrated in Fig. 1. To expand somewhat on these categories, Table I lists a representative selection of the materials combinations now in reactor service in the United States or manufactured by U. S. firms.

TABLE I

NATURE OF URANIUM FUEL AND CLADDING MATERIAL IN NUCLEAR REACTORS

Name and Location	Startup	Cladding Material	% ^{235}U Enrichment	Fuel Material
Bulk Shielding Reactor, Oak Ridge, Tenn.	1950	Al	93	Uranium-Aluminum Alloy
Low-Intensity Training Reactor, Oak Ridge Tenn.	1950	Al	93	Uranium-Aluminum Alloy
Materials Testing Reactor, NRTS, Idaho	1952	Al	93	Uranium-Aluminum Alloy
Geneva Conference Display Reactor, Geneva, Switzerland	1955	Al	20	UO_2 Dispersed in Aluminum
Stationary Medium Power Reactor (APPR) Fort Belvoir, Va.	1955	SS	93	UO_2 Dispersed in SS
Engineering Test Reactor, NRTS, Idaho	1957	Al	93	Uranium-Aluminum Alloy
Vallecitos Boiling Water Reactor, Pleasanton, Calif.	1957	SS	93	UO_2 Dispersed in SS
Shippingport Atomic Power Station, Shippingport, Pa.	1957	Zircaloy	93	Uranium-Zirconium Alloy
Oak Ridge Research Reactor, Oak Ridge, Tenn.	1958	Al	93	Uranium-Aluminum Alloy
Dresden Nuclear Power Station, Morris, Ill.	1959	Zircaloy	1.5	Pelletized UO_2
Puerto Rico Nuclear Center, Mayaguez, Puerto Rico	1960	Al	20	U_3O_8 Dispersed in Aluminum
Yankee Nuclear Power Station, Rowe, Mass.	1960	SS	3.4	Pelletized UO_2
Consolidated Edison Thorium Reactor, Buchanan, N. Y.	1962	SS	93	Pelletized $\text{ThO}_2\text{-UO}_2$
Hallam Nuclear Power Facility, Hallam, Neb.	1962	SS	3.6	Uranium Molybdenum Alloy
Elk River Reactor, Elk River, Minn.	1962	SS	93	Pelletized $\text{ThO}_2\text{-UO}_2$
SENN, Gargliano River, Italy	1963	Zircaloy	2.0	Pelletized UO_2
Enrico Fermi Atomic Power Plant, Lagoona Beach, Mich.	1963	Zr	25	Uranium Molybdenum Alloy
High Flux Isotope Reactor, Oak Ridge, Tenn.	1965	Al	93	U_3O_8 Dispersed in Aluminum

CONTROL PROCEDURES

The development and fabrication of the many and varied types of fuel elements over the past 15 years at Oak Ridge National Laboratory have afforded an excellent opportunity for a parallel development and testing of materials control procedures. Reliable techniques for handling enriched fuel in alloy, dispersion, and bulk oxide form were developed and, in many cases, adopted directly as standards for subsequent commercial fabrication of these elements.

In every fabrication program, successful control was achieved by establishing a unit procedure in the areas of (1) starting material in the as-received form, (2) fabrication of components, (3) component processing, and (4) scrap handling; these were tied together into a control summary so that the entire effort could be examined and analyzed.

Control of Starting Material

Control must begin immediately upon receipt of the uranium materials. These materials fall into two general categories: solid metals and powdered materials. Solid metals include both pure uranium and alloys, since the fabricator will sometimes avoid the melting and casting step by procuring prealloyed uranium. Powdered materials include such compounds as UO_2 , UN, and U_3O_8 , which are not alloyed but mechanically mixed with diluent. For bulk oxide fabrication, the fabricator may receive premixed compounds, such as $\text{UO}_2\text{-ThO}_2$, $\text{UO}_2\text{-BeO}$, $\text{UO}_2\text{-C}$, and Si-SiC-UO_2 .

Verification. - Three quantities of the material should be listed in its accompanying documents: net weight of the uranium-bearing material, total uranium contained in the material, and the total ^{235}U based on enrichment. Verification of all three figures is important to the fabricator, not only because the materials are expensive but also because the fuel may not meet specifications.

Net weight is verified with balances, accurate to no less than ± 0.5 g for the higher enrichments. Total uranium can be chemically verified by potentiometric titration analysis. Isotopic enrichment is verified by mass spectrometry. If the fabricator receives alloyed

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or premixed material, he must develop and use reliable sampling techniques to ensure that the uranium is both in the proper proportion with the matrix material and homogeneously dispersed.

Handling and Storage. - The uranium materials, received in a critically safe container as shown in Fig. 2, are removed and check-weighed on suitable balances. Metals may be placed directly on the balance. Powdered compounds, however, must remain in their inner containers on the balances or be check-weighed in a contained area, such as a dry box, to protect the operator from toxicity and prevent contamination. It is often advantageous for the fabricator to supply his vendor with permanently tared inner containers so the filled container can be check-weighed.

Control Records. - Materials are usually processed by the fabricator in smaller batches than received. Control of the starting materials requires knowing how much material has been received, how much has been assigned to process, and how much is on hand. The preferred initial control is the simple in-out-balance perpetual inventory. To facilitate immediate materials tracing, however, it should include references for each quantity received and the process batches to which the smaller quantities have been assigned.

Fabrication of Components

"Primary fabrication" includes all stages in which the fuel materials are being processed for containment in nonfuel metals. When uranium-aluminum alloy fuel plates are fabricated, for example, the uranium is first dispersed in aluminum by melting, and the alloy is cast in a graphite mold. The ingot is then reduced in thickness by rolling. Fuel cores are punched from the rolled plate, pressed into an aluminum frame of similar thickness, and covered with aluminum plates to form a composite "sandwich" (Fig. 3). Now the primary fabrication is complete. The fuel is contained within a composite fuel plate and cannot be altered in weight or content except by destruction of the component.

Often alloy fuels are impractical or impossible to fabricate, so that the fuel core is fabricated by dispersion of a powder. For example, aluminum alloys containing more than 30% U are very difficult to fabricate, and useful concentrations of uranium cannot be incorporated in stainless steel by alloying. In the powder dispersion method, the fuel

compound and matrix are formed into a fuel compact by blending, cold pressing, sintering, and coining. This method permits excellent distribution of fuel and extremely accurate accounting for the critical ingredients. Also, the fuel components have two chief advantages over the alloy: (1) greater freedom of selection of fuel and matrix material for better performance characteristics and (2) confinement of the fission product damage to the fuel compound, so that the matrix can better carry the in-service structural load.

Bulk oxide or other ceramic compound component fabrication involves ceramic and metallurgical techniques similar to those used in the dispersion method. Although the amount of fuel material in the component must be exact, the control is relatively simple since no fuel-matrix relations are involved and, in this regard, homogeneity is no problem.

Specification. - In both alloy and dispersion fabrication, one must predetermine uranium content in the core materials to obtain the desired ^{235}U content in the final component. Aronin and Klein [1] have shown that the density method can be utilized with a high degree of accuracy in determining proper composition of uranium-aluminum alloys. Their work has shown a correlation between calculated percentage by weight and analytical results within $\pm 0.19\%$ in alloys containing up to 35% U. However, Martin and Leitten [2], at the Oak Ridge National Laboratory, showed that suppression of UAl_3 formation in the alloy is difficult at the higher uranium percentages and that the correlation becomes inadequate above 24 wt % U.

When the dispersion technique is used, the predetermination becomes even more difficult because of the additional variables involved. These variables, which have a direct effect on the density of the fuel core compact, include the uranium content of the fuel compound and the size, shape, and density of both the fuel and matrix particles.

Where homogeneous fuel cores are the same size and fabricated from a single melt, the average weight method for determining fuel content in each component is very reliable. The entire batch of components from a single heat is weighed and total weight divided by their number. If an extremely close tolerance is desired, the content is determined from a density measurement of each component.

Verification. - A pilot fabrication effort with liberal destructive testing of the end products will be used by the fabricator before actual production begins. This facilitates prediction of the end result with enough certainty to assure general control during actual production and, in many cases, is one of the best methods of product verification. Homogeneity of dispersion products, for instance, is often based on integrity of the process and depends almost wholly on intelligent operation and close control during fabrication. Even though many advances have been made in the field of nondestructive testing for confirming homogeneity, fuel quantity, and other specifications [3], any such control methods remain secondary to process integrity.

In alloy fabrication, however, content may be verified by wet chemical analysis of dip samples taken from each melt before casting. The samples are very representative, and measurement at this early stage permits some adjustment of the uranium content by adjusting the thickness of the fuel compact before primary fabrication is complete.

These analyses must be evaluated to determine if the uranium content of the material is acceptable. The establishment of criteria for acceptability depends on two uncertainties in alloy content determination: (1) the disagreement between the chemical analysis and the intended composition and (2) the limits of error in the sampling and analysis. These must be examined collectively to determine if the fuel content specification has been met. The average analytical result rather than the intended composition is depended on to correct any mechanical or human errors that have occurred in the process.

Control Records. The form records used in the control of enriched uranium during the primary fabrication process differ from plant to plant even more widely than do the fabricated shapes they control. In every case, however, they should answer three basic control questions:

- (1) Where is the material located?
- (2) What is its physical shape?
- (3) What is its quantity in relation to the matrix materials in which it is dispersed?

Figure 4a illustrates a practical log that records the desired information and supplies the necessary control facts. This form is readily adaptable to other alloy fabrication, such as the casting and extrusion

of rods, since the same facts are required. Note that the uranium percentage applied to the net alloy weights is the average of the analyses of the dip samples. Note also that a great deal of information has been practically condensed into a single control record and reflects the relationship of the categories in a single presentation.

The type of control record used for dispersed fuel materials is very similar (Fig. 4b). Since there are fewer steps, the record is somewhat simpler. It does, however, adequately reflect the steps and provide the necessary control information. The same form is also useful for the primary step in bulk oxide fabrication.

Component Processing

"Secondary fabrication" relates to work on the fuel components after they are completely contained in nonfuel metals. Since changes in the uranium content of the components are now impossible without their destruction, material control becomes relatively simplified; only a piece identification is necessary.

The most difficult task in controlling secondary materials is to maintain identification of small, individual components until they can be permanently marked. The use of batch containers is a good method for maintaining identification as well as transporting the pieces through the early stages of secondary processing when the components are in groups of identical pieces and can be interchanged. Such a container should be compartmented to accommodate any rejected pieces as they occur in the process. Once the components have been permanently marked, usually by etching or stamping, the batch container is no longer needed and can be diverted to new batches of components.

Control of the Final Assembly. - If several of the small components are to be further processed into a fuel assembly, control shifts from individual component identification to assembly or fuel element identification. Components from different batches will often be mixed to attain fuel content within a close tolerance. The control shifts when the plates are selected and temporarily assembled by taping or tying and should be so recorded.

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Control Records. - Secondary fabrication records fall into three categories: (1) component processing records, (2) component disposition records, and (3) assembled component records.

Figure 4c illustrates a record for controlling the materials during component processing. This batch control record accompanies its group of components through all stages of processing, accounting for the components, and collecting information concerning rejections. When complete, the record is filed with the previous batch log (Fig. 4a or b) and the two serve as a complete materials and process control from receipt of the starting materials through component processing. If desired, the two cards may be merged into a single control record which is initiated with the starting materials.

At this point, the fuel components may be finished products or may require further assembly into multicomponent units. In either case, a record should be made to indicate the disposition of the finished accepted components. Figure 5a is a record that initially records the temporary storage of a finished component batch. Their shipment, or further processing into assembled units, is indicated as it occurs, and their disposition is permanently recorded.

Materials control during assembly is very similar to batch control. A record is made of those components selected for assembly into an element and follows them through the assembly process. The element assembly record, illustrated in Fig. 5b was originally designed for the collection of data during assembly of an MTR element containing curved plates. This record is also a good illustration of how one may integrate the maximum number of controls into the minimum number of records to eliminate duplication.

Scrap Handling

Scrap materials, which can occur at any time during the fabrication process, must be disposed of by either recycling through the process or reclaiming through chemical recovery. When economically feasible, scrap may be buried or otherwise safely destroyed; this rarely occurs, however, with the use of highly enriched material.

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Alloy residues of good quality can be remelted with additional uranium and aluminum to form a new ingot, so chemical recovery is not economically feasible unless the process is closed. Rejected components can often be remelted with the alloy residues if no contaminants that would damage the new alloy are present in the cladding materials.

Some residues, like heat dross from the top of the alloy melt, contain so many impurities that they must always be removed from the process and recovered. Also, rejected powder compacts can be recovered only by chemical means.

Since enriched scrap usually occurs in relatively small amounts, it is recovered most inexpensively by accumulating several small quantities into a larger batch for a single recovery operation. Such a batch is, of course, limited by criticality considerations.

Control Summary

The final control procedure in the fabrication of enriched uranium dictates a summary and general examination of the entire process. The total amount of uranium material that has entered the fabrication plant must be compared with the total amount on hand after processing, and process differences must be determined. In addition, all records should be examined to ensure that product specifications have been met and analyzed for any trends that would affect the process or components.

The Material Balance. - The materials before and after processing are best compared by the material balance. In this method, the process is either actually or theoretically cut off at a selected point. Usually, an actual cutoff occurs only if the product is changing and different specifications are involved (such as a different uranium enrichment), necessitating an equipment cleanup and resetting or retooling. Pure and unclad materials are weighed and counted and their uranium content is computed. The clad or contained materials are counted and identified, and fuel content is established from their fabrication records.

On completion, the inventory is checked against closing balances indicated on all previously discussed control records. The inventory listings are posted to a previously prepared worksheet which already bears the ending control record balances. In some cases, this worksheet

is given to the personnel taking the inventory as a guide; but when this is done the advantage of a "blind" inventory requiring a thorough search is lost.

The uranium content values computed for the inventoried materials listed on the worksheet are now summed and drawn into an actual balance against all materials charged to the plant (Fig. 5c).

Process Differences. - Note that the uranium content of the heat dross in this particular balance is determined three ways: as the uranium percentage in the alloy, as the difference between inventory and book balance, and as the actual recovered content. Only the last is significant in determining the normal process differences that will occur, as the impurities in the heat dross will vary rather extensively from batch to batch. Indeed, on first drawing the balance using the percentage, one will more often experience a process gain rather than a process loss, a good first indication that the final balance will fall within acceptable limits of error if such a gain is small.

What, then, are acceptable limits of error for the process? The answer to this question is tied directly to two considerations: (1) the collective measurement limits of error for the process and (2) the fuel specifications of the fabricated products. If the process difference falls within these limits it is a reasonable one. If it does not, individual process circumstances must be considered and the process records must be reexamined to isolate the process stage or stages where it occurred. Sometimes, additional checks must be made, such as x-ray examination, further component sampling, or a chemical analysis of the related backup dip samples. In any case, the fabricator must be satisfied as to the product fuel content, for there is no practical adjustment after the component has entered the reactor.

Process losses of raw material also affect the product cost, especially when expensive enriched uranium is the raw material. If a relatively large process loss occurs, even though the components meet specifications satisfactorily, the cost of enriched uranium requires that the process be reexamined and adjusted to make any possible reduction of this loss.

Process Evaluation. - In addition to a recheck of all measurements and values reflected in the process records, a thorough analysis and evaluation of the total data are important. Such factors as dimensions consistently on the high side set patterns of intended fuel content versus intended result, and, constant recurrence of unusual effects or normal defects will often reflect areas in the process requiring further development work.

Another important aspect of any fabrication effort is the maintenance of a good ratio of product yield to materials processed. The scrap, waste, and yield record (Fig. 5d) illustrates a good approach to determining this ratio. It also provides a scrap analysis for determining process trouble spots.

SUMMARY

Control of enriched uranium during its fabrication is important because of the scarcity, expense, and special hazards of the material, and because technical success in the manufacture of reactor fuel elements depends on how well its controls are designed and applied. The relation of these factors to the particular fabrication process must be considered before one can properly select and establish controls for that process. The basic objectives in control system design include completely integrated records for a minimum number of material units in each major fabrication step confirmed by reliable cross checks.

Control procedures must be established to provide data needed for the ultimate material balance. From this summary, process gains or losses are determined which either confirm the product fuel content or indicate the need for further examination of the control data and fuel components.

Two other results are evident in developing proper control procedures. First, as production proceeds, the number of units to be controlled decreases; and the higher the rate of decrease, the more efficient and simplified the control procedure becomes. Second, the data generated during the control process can form significant patterns that point to possible trouble spots in the fabrication effort.

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FIGURES

- Fig. 1. Representative Fuel Element Types. Refs. (a) J. E. Cunningham and E. J. Boyle, "MTR Type Fuel Elements," Progress in Nuclear Energy 1(V), McGraw-Hill, New York (1956), 544-550. (b) J. E. Cunningham et al., Specifications and Fabrication Procedures for APPR-1 Core II Stationary Fuel Elements, USAEC Report ORNL-2649, Oak Ridge National Laboratory, Jan. 29, 1959. (c) Personnel of the Naval Reactors Branch, The Shippingport Pressurized Water Reactor, Addison-Wesley, Reading, Mass., (1958), 78-84, 151-158.
- Fig. 2. Metal "Bird Cage" Type Shipping Container. Uranium materials are placed in the center container for shipment. Criticality spacing is maintained by the outer frame.
- Fig. 3. Exploded View Showing Makeup of Fuel Composite. Dimensions are approximate and will vary with specification.
- Fig. 4. Typical Records Used in Uranium Materials Control. (a) Alloy Heat Log. (b) Blended Materials Batch Log. (c) Batch Control Card.
- Fig. 5. Typical Records Used in Uranium Materials Control and the Material Balance. (a) Component Disposition Record. (b) Fuel Unit Fabrication Record. (c) Uranium Material Balance. (d) Scrap, Waste, and Yield Record.

Fig. 2. Metal "Bird Cage" Type Shipping Container. Uranium materials are placed in the center container for shipment. Criticality spacing is maintained by the outer frame.

Fig. 3. Exploded View Showing Makeup of Fuel Composite. Dimensions are approximate and will vary with specification.

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Fig. 1. Representative Fuel Element Types. Refs. (a) J. E. Cunningham and E. J. Boyle, "MTR Type Fuel Elements," Progress in Nuclear Energy 1(V), McGraw-Hill, New York (1956), 544-550. (b) J. E. Cunningham et al., Specifications and Fabrication Procedures for APFR-1 Core II Stationary Fuel Elements, USAEC Report ORNL-2649, Oak Ridge National Laboratory, Jan. 29, 1959. (c) Personnel of the Naval Reactors Branch, The Shippingport Pressurized Water Reactor, Addison-Wesley, Reading, Mass., (1958), 78-84, 151-158.

(a)

ALLOY HEAT LOG				
Heat No.	Type Material	Intended wt % U	wt % U by Arg. Chem. Analysis	Fabrication Order No.
E-514	U-Al Alloy	15.95	15.97	1124 RPB
BEGINNING MATERIALS				
Type Material	Identification	Net Weight	Total U	U ²³⁵
Uranium Metal	IC-842	720.14	720.14	648.13
Alloy Scrap	E-497	1654.12	239.02	215.12
Scrap Components 3 Plates	E-492	591.22	25.17	22.65
Scrap Components 2 Plates	E-494	393.68	16.74	15.07
Scrap Components 2 Plates	E-500	397.10	20.13	18.12
Other Matrix	High Purity Al Metal	2646.22	-	-
Other Material				
Total Materials		6402.48	1021.20	919.09
ALLOY PRODUCTS				
Alloy Billets (2)	E-514	6096.28	973.58	876.22
Alloy Samples	#1 AR 15.99	6.62	1.06	0.95
	#2 AR 15.96	6.40	1.02	0.92
	#3 AR 15.95	4.57	0.73	0.66
Waste Products	Heat Drain	315.80	50.43	45.39
Total Alloy Products		6429.67	1026.82	924.14
Beginning Materials - Alloy Product Difference		+27.19	+5.62	+5.06
COMPONENT PRODUCTS				
No. Acceptable Pieces	76 Cans	4482.91	715.92	644.33
Average Weight Piece		(58.98)	(9.42)	(8.48)
Scrap Materials	After Punching	1611.24	257.32	231.58
Waste Materials				
Total Products		6094.15	973.24	875.91
Alloy - Component Difference		-2.13	-0.34	-0.31
AR - Analytical Result				

Fig. 4. Typical Records Used in Uranium Materials Control. (a) Alloy Heat Log. (b) Blended Materials Batch Log. (c) Batch Control Card.

(b)

BLENDED MATERIALS BATCH LOG				
Blend No.	Type Material	wt % Uranium	Fabrication Order No.	
EB-284	UO ₂ -Aluminum	48.00	1127	RJB
BEGINNING MATERIALS				
Type Material	Identification	Net Weight	Total U	U ²³⁵
Uranium UO ₂ Powder	IC-927	1011.63	890.23	178.05
Residue from Previous Blend	EB-283	12.21	5.86	1.17
Matrix Material	Al Powder	843.01	-	-
Other Material				
Total Blend		1866.85	896.09	179.22
COMPONENT PRODUCTS				
No. Acceptable Pressed Comp.	19	1759.42	844.52	168.90
Average weight Acceptable Comp.	-	(92.60)	(44.45)	(8.89)
Rejected Components	1	92.60	44.45	8.89
Unused Blend Residue		10.61	5.09	1.02
Total Component Products		1862.63	894.06	178.81
Blend-Component Difference		4.22	2.03	0.41

(c)

BATCH CONTROL CARD			
Batch No. E-514			
Number Components 76		Type U-Al Alloy Plates	
Stage	Processed By	Rejections and Reason	Inspected By
1. Frame	BNC	OK	WJW
2. Cover	BNC	OK	WJW
3. Can	-	-	-
4. Weld	AW	OK	AK
5. Hot Roll	CHW	OK	HQW
6. Cold Roll	CHW	1-0.057	HQW
7. Anneal	JNH	2-Blisters	WWP
8. Fluoroscopy	JWB	3-Cans off Tol.	JWB
9. Shear	JWB	OK	JWB
10. Machine	CPR	OK	AK
11. Anneal	JNH	1-Blisters	WWP
12. Inspect	WWP	1-Thin Edge	WWP
Total Accepted Components to Storage.		68	
Total Scrapped Components		8	

SPECIFICATION
COMPLIANCE

COMPLETED COMPONENT DISPOSITION RECORD						
Heat or Batch No. <u>E-514</u>		Average Total U Each Component			<u>9.41</u>	<u>U²³⁵ 8.48</u>
Disposition	Date	Number Components			Balance on Hand	
		In	Out	Bal	Total U	U ²³⁵
Received for Storage	6-12-58	68	-	68	640.56	576.64
<u>Element I-109</u>	6-14-58		12	56	527.52	474.88
<u>Shipment 1142-1</u>	6-15-58		27	29	273.18	245.92
<u>Element I-121</u>	6-24-58		16	13	122.46	110.24
<u>Element I-123</u>	6-25-58		9	4	37.68	33.92
<u>Element I-127</u>	6-27-58		4	0	-0-	-0-

ENRICHED URANIUM MATERIAL BALANCE		
Period: July 1 - 31	Total Uranium Grams	U-235 Grams
Type Material: 90% Enriched Uranium Alloy		
Balance on Hand, June 30	17,037	15,333
Total Receipts - July	25,274	22,747
Total Previous Balance and Receipts	42,311	38,080
Less Total Shipments - July	16,426	14,783
Balance on Hand, July 31	25,885	23,297
Materials Inventory		
Beginning Materials:		
Metal	3,421	3,079
Materials in Process:		
Billets	2,652	2,387
Rods	1,381	1,243
Cores	1,829	1,646
Remelt Alloy from Punchings	1,545	1,391
Product Materials:		
Plates	6,737	6,063
Assembled Element	7,347	6,612
Scrap Materials for Recovery:		
Heat Dross		
By Weight and % Uranium	998	
By Difference	973	
Recovered	924	832
TOTAL INVENTORY	25,836	23,253
Process Difference (Loss)	49	44

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PLATE DATA							PLATE SPACING, MILS					CRITICAL DIMENSIONS, INCHES					
Heat No.	Plate Length	No. Plates	Total U Per Plate	U-235 Per Plate	Total U	Total U-235	Space No.	Location, Inches				Pt.	A	B	C	VCH Sagitta	
E-501	Long	2	8.697	7.795	17.394	15.590	1-2	118	122	121	120	2 1/2	2.991	2.988	2.991	3.070	0.242
	Long						2-3	116	113	112	119	7	2.993	2.990	2.994	3.068	0.240
E-504	Reg.	1	8.683	7.783	8.683	7.783	3-4	119	115	116	115	12	2.995	2.990	2.994	3.069	0.240
E-505	Reg.	4	8.707	7.804	34.828	31.216	4-5	117	117	117	116	16	2.995	2.990	2.994	3.065	0.246
E-508	Reg.	11	8.738	7.832	96.118	86.153	5-6	118	112	113	117	21	2.995	2.991	2.993	3.065	0.248
	Reg.						6-7	117	123	121	119	26 1/2	2.992	2.988	2.990	3.073	0.240
Grand Total	18		Total U-235 in Assembly			140.741	7-8	118	117	122	117	Plate Spacing 117 Mils ± 12					

SPECIAL ELEMENT PLATE POSITIONING

☒ POSITIONED AS CHECKED

☐ NOT APPLICABLE

☐ TOP OF ASSEMBLY

☐ BOTTOM OF ASSEMBLY

9-10	116	116	111	118
8-9	117	118	120	119
10-11	118	119	121	118
11-12	119	119	122	117
12-13	116	114	108	116
13-14	119	119	120	118
14-15	117	118	112	119
15-16	117	115	120	117
16-17	118	126	119	120
17-18	122	113	120	123
18-19	—	—	—	—

Plate Thickness: Side Plates $\frac{3}{16}$ inch
Center Plates 0.062 inch
Outer Plates 0.062 inch

Side Plates: ☐ Bronze Clad ☒ Bronze Metal

Remarks:

18 Curved plate assembly
Long top and bottom plates.

Plate Content based on
average analysis of dip
sample taken from heat.

SCRAP, WASTE, AND YIELD RECORD														
Uranium Chloride Alloy For Period July 1, 1958 to July 8, 1958 70% U ²³⁵														
Batch No.	No. Comp. Fab.	Rejections For					Total	No. Re-cycled	For Recovery - Calculated Value			Actual Recovery		Process Differences
		1	2	3	4	5	6		No.	Net Weight	Total U	U ²³⁵	Total U	U ²³⁵
E-514	76	3	1		3	1	8	8						
E-514									10	315.80	50.43	45.39		
E-515	76	2		1	4		7	7						
E-515									10	289.79	62.07	55.86		
E-516	74	1		3		1	4	9						
E-516									10	326.51	50.45	45.41		
E-517	76	2			1		3	3						
E-517									10	297.45	54.76	49.28		
E-518	76		1			2	3	3						
E-518									10	342.81	63.11	56.80		
Totals	378	8	2	4	4	8	4	30		1572.36	280.82	252.74	252.73	227.46 -28.09 25.28

Fig. 5. Typical Records Used in Uranium Materials Control and the Material Balance. (a) Component Disposition Record. (b) Fuel Unit Fabrication Record. (c) Uranium Material Balance. (d) Scrap, Waste, and Yield Record.