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MATERIAL ACCOUNTANCY FOR METALLIC FUEL PIN CASTING*

by

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ABSTRACT

The operation of the Fuel Conditioning Facility (FCF) is based on the electrometallurgical processing of spent metallic reactor fuel. The pin casting operation, although only one of several operations in FCF, was the first to be on-line. As such, it has served to demonstrate the material accountancy system in many of its facets. This paper details, for the operation of the pin casting process with depleted uranium, the interaction between the mass tracking system (MTG) and some of the ancillary computer codes which generate pertinent information for operations and material accountancy. It is necessary to distinguish between two types of material balance calculations--closeout for operations and material accountancy for safeguards. The two have much in common, for example, the mass tracking system database and the calculation of an inventory difference, but, in general, are not congruent with regard to balance period and balance spatial domain. Moreover, the objective, assessment, and reporting requirements of the calculated inventory difference are very different in the two cases.

INTRODUCTION

An integral part of the Fuel Conditioning Facility (FCF) is the mass tracking system (MTG).[1] This system tracks, in both space and time, all process materials as they enter, pass through (are processed and stored in), and exit the facility. The information in the mass tracking system is central to the operation of the facility and to material accountancy for safeguards. The first FCF process to be on-line was the pin casting operation. As such, it has served as the initial demonstration of the material accountancy system.

The data for this demonstration of material accountancy were taken from the pin casting operation DU03, which was performed at the FCF from January 5 through 13, 1994. The operational steps of the pin casting are shown in Fig. 1, in time, along the vertical axis and in space, from process zone to process zone, along the horizontal axis; the material balance period and the material balance area are also indicated.

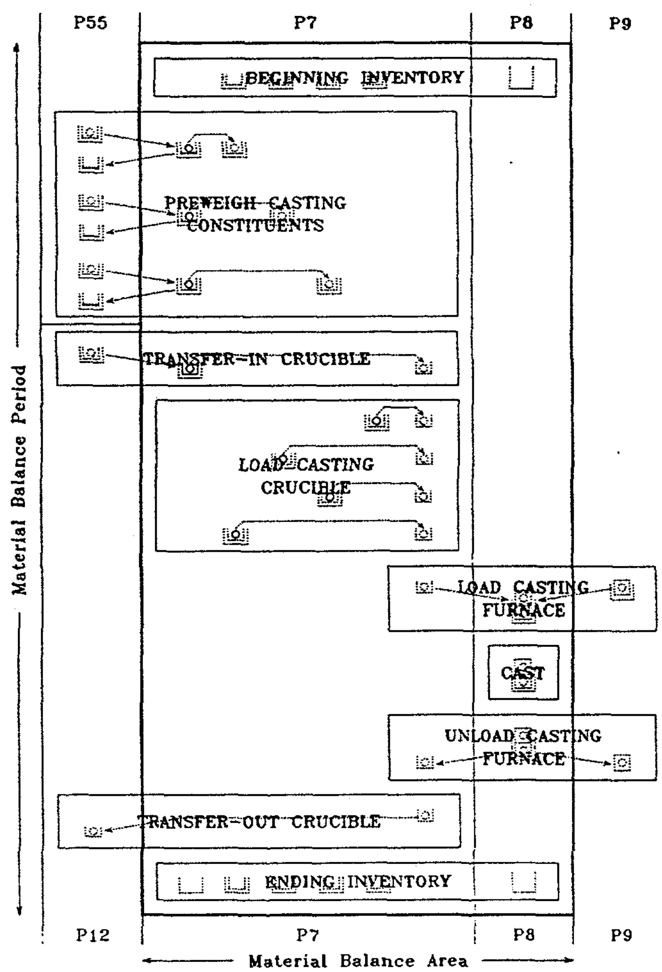

Fig. 1. Pin Casting Material Balance

In order to exhibit the details present in the mass tracking system database and material accountancy report, a portion of the preweigh casting constituents step is represented in Fig. 2. In these operations, the container MMB003, with the inner container URC003 and makeup uranium 931221151002 contents, is transferred from the Storage Zone P55 to the Casting Charge Preparation Zone

P7; the process material is transferred to another set of process containers (not shown) within P7; and the container MMB003, with the inner container and its process holdup, is returned to P55.

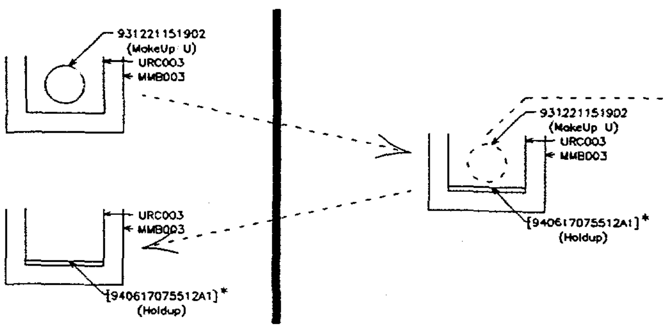

Fig. 2. Transfer Operations During Preweigh Casting Constituents Step

MASS TRACKING SYSTEM DATABASE

The dossier for the history of each item and a register of all activities in the FCF are contained in the Oracle(2) tables and ISOZ files of the Mass Tracking System database. The principle tables are the Item, Location, Weight, and Transfer tables.

In brief, the Item Table contains for each item that exists or has existed in the facility the form and type description, the birth and death date-times, and a pointer to the binary ISOZ file that specifies the item's isotopic composition and measurement information. In the MTG, items are process material, containers, equipment, and even the facility's storage units, process zones, and cells. The Location Table provides a nested sequence of present and past locations for all items with the date-time interval during which the item resided at the respective location. The Weight Table records all container weights and the identification of the balance used, with cross references to the container's most recent tare and clean tare measurements and any tare setting that may have existed on the balance at the time of the weighing.

Details of all transfers are stored in one of the Transfer Tables. The Zone-to-Zone Transfer Table includes the identification of the transferred container and its destination, the source and destination zones, the request and completion date-times, and a pointer to the confirmation weight required for each transfer. The Container-to-Container Transfer Table contains the source and destination containers, the request and completion date-times, and the transfer type; for certain types, the date-times designating the initial and final weighings of the source and destination containers and the initial tare of the source container are also present.

MATERIAL BALANCE: CLOSEOUT VS. ACCOUNTANCY

It is necessary to distinguish between two types of material balance calculations utilized by FCF--closeout for operations and material accountancy for safeguards. The two have much in common, for example, the mass tracking system database and the calculation of an inventory difference, but, in general, are not congruent with regard to balance period and balance area. Moreover, the objective and assessment of the calculated inventory difference is very different in the two cases.

The FCF operates in a batch mode with a distinct sequence of operations. At the completion of an operational step, the success of the operation, and permission to proceed to the next step, are evaluated with respect to the closeout inventory difference calculated for the process step. The criteria with which the inventory difference is judged are based on operational considerations. Successful closeout also indicates acceptance of the data collected during the operation into the mass tracking system database.

While closeout is associated with an operational step, the inventory difference calculation for material accountancy is not limited to the same spatial domain and time period. In principle, it could be calculated, based on the data in the mass tracking system, over any material balance area and any balance period, whether less or more than one operational step. In this analysis the operation consists of only one process--pin casting. Thus, there is little distinction between the closeout and accountancy balance areas and the balance periods.

A second distinction between closeout and material accountancy concerns the source of the data for the inventory difference calculation. The on-line closeout report utilizes the compositions of process materials derived from computational models of the process, and possibly even estimates of the item masses. Although material accountancy for safeguards can likewise be performed in near-real-time using these same data, the more meaningful analysis occurs subsequent to the introduction of analytical chemistry measurements or off-line volume determinations into the MTG database via the replay feature which updates the compositions of the sampled item and all items created from this item.

PROCEDURE FOR COMPUTATION OF MATERIAL BALANCE

Upon completion of an operational step, such as pin casting, a task closeout is executed and a closeout report is written. The facility elements needed to perform this task, and their interaction, are shown in Fig. 3. Closeout is initiated by an operator at an Operator Control Station (OCS) issuing a command through the communication file to the system of MTG tasks; for the pin casting operation, the particular task is CAST. This computer code, on the basis of the data in the MTG database, calculates the masses of process material and holdup in each container used in the operation. The closeout report presents, for each container, the location, the content's description, the total net mass, and the mass by element and isotope at the beginning, and at the completion of the operation. An inventory difference is also given for the net weight, elemental U and Pu, and fissile isotopes U-235 and Pu-239.

The elements required to compute a material balance for safeguards are shown in Fig. 4. The accountancy calculation is initiated with an input communications file which specifies the material balance area, the material balance period, and the isotopes for which an inventory difference is to be calculated. The MTG task MCADAT is executed to retrieve from the database and to return in the output communications file the pertinent accountancy information. The task also writes the material balance report which includes a detailed description of the initial and final inventories and of the transfers into and out of the material balance area over the accountancy period as well as the estimate of the inventory difference.

Material accountancy, however, also requires an estimate of the uncertainty in the inventory difference. The information with regard to measurement errors, on which this estimate is based, are propagated through the inventory difference calculation via the computational engine--the code MAWST.[3] Since the MTG system was developed independent of MAWST, the MCADAT output communications file must be processed by the interfacecode MAMI to create the measurement value file for input to MAWST. The code MAMI also processes the measurement errors derived from instrument calibrations to create the MAWST input measurement error file. The measurement methods file, which specifies the partition of the propagated variance into user-defined categories, is the

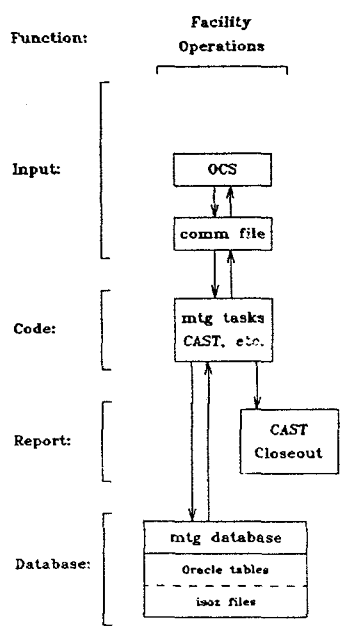

Fig. 3. Schematic for Operations

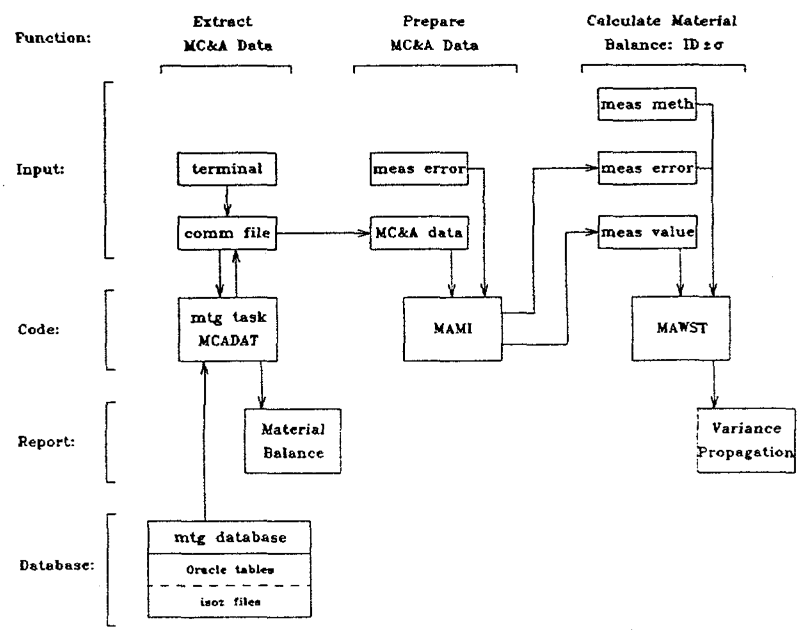

Fig. 4. Schematic for Material Accountancy

final MAWST input file. MAWST generates the variance report containing the material balance variance, the total and by category, in addition to the inventory difference, its standard deviation (1σ) and its limit of error (2σ). The inventory difference quoted in the material balance report from MCADAT is checked against the MAWST computations.

MATERIAL ACCOUTANCY FOR PIN CASTING OPERATION

As shown in Fig. 1, the material balance area is the Casting Charge Preparation Zone P7 and the Casting Furnace Zone P8; the accountancy period begins at 01/05/94 - 12:00, prior to the initiation of the charge preparation, and ends at 01/13/94 - 14:00, subsequent to the transfer of the casting crucible and casting heel to the General Work Station Zone P12. The isotopes of interest in this accountancy demonstration are U-235 and U-238. This analysis incorporates the results of analytical chemistry on several segments of a single cast pin; the measured isotopic composition was assigned to the final casting charge and replayed through the database.

An edited version of the material balance report for this pin casting operation is shown in Fig. 5; the report has been shortened, inserting hyphens at points from which blocks of entries have been deleted, but retains the essential features and sufficient entries to understand the inventories and transfers illustrated in Figs. 1 and 2.

The MAWST input measurement error file for U-238 and the measurement methods file are presented in Figs. 6 and 7, respectively. The measurement error file specifies, for each instrument used for an accountancy measurement, the error model (1 for absolute, 2 for relative), the calibration period (a relative index), and the random and systematic one-sigma uncertainties (in grams or percent, depending on the error model).

The MAWST variance report for U-238 is given in Fig. 8; the inventory difference is 2.7 gm with a limit of error of 322.9 gm. The inventory difference is well within the limit of error. The dominant contribution to the variance of the inventory difference comes from the chemistry analysis. This error contribution is three orders of magnitude greater than that of the electronic balances for mass measurements.

In the case of U-235, the inventory difference is -1.96 gm with a limit of error of 1.49 gm. Two observations are clearly evident. The first, that the inventory difference is negative, implying a gain in U-235. The other, that the limit of error is less than the estimate of the inventory difference, implying the estimate of the inventory difference is statistically significant. That the estimate of the inventory difference is negative, in itself, is not surprising. We would expect, on the average, if there truly are no gains or losses, half of the estimates for the inventory difference to be negative. That the estimated limit of error indicates this result to be statistically significant, requires closer scrutiny.

A clear clue is the fact that the variance in the estimate of the composition, i.e., the isotopic, is the dominant contribution to the limit of error. Since the DU03 casting involves depleted uranium, the U-235 isotope is present in almost trace amounts (0.2%). The uncertainty associated with the chemistry analysis in this calculation does not reflect the increase in the uncertainty in the U-235 fraction estimate due to its low concentration. An increase in the isotopic fraction error from 1.5% (relative error), the value in the material balance calculation, to 2.0% results in a limit of error equal to the inventory difference estimate. The apparent anomaly in the U-235 result can be resolved by taking into account the variation in the error at low concentrations.

The inventory difference for U-235 in the MAWST variance report (in gms) and the MCADAT material balance report (in kgs) are in agreement. The minor difference (0.1 gm) for the corresponding total uranium values reflect insignificant computational errors.

SUMMARY

The operation of the FCF accountancy system has been demonstrated in detail for a metallic fuel pin casting operation. This first casting operation in FCF with depleted uranium generated data to exercise the interaction between the mass tracking system and some of the ancillary codes which process the pertinent data for operations and material accountancy. The material accountancy system of the FCF was shown to be effective in handling two types of material balance calculations--closeout for operations and material accountancy for safeguards.

Material Balance Report: 07/12/94 - 14:41:28
Material Balance Area: CHCS Zones P7, P8
Material Balance Period: 01/05/94 - 12:00:00 to 01/13/94 - 14:00:00
Material Balance Isotopes: 92-235, 92-238
Material Balance weight data are based on signature weights.

Initial Inventory:

Zone	Item ID	Type	Form	Net Weight	total Kg. U	% U enrich	Kg. U-235	total Kg. Pu	Kg. Pu-239	SPM number
P7	FHC001	FissOuterHsg	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	LWC002	LowWrthFiss	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	FHCX01	FissOuterHsg	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	LWC001	LowWrthFiss	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	931220171723	Zirconium	MakeUp	1.4528	0.0000	0.0000	0.0000	0.0000	0.0000	
	Total			1.4528	0.0000		0.0000	0.0000	0.0000	
	Total Initital Inventory			1.4528	0.0000		0.0000	0.0000	0.0000	

Transfers In:

Dest/Term Zone	Item ID	Type	Form	Net Weight	total Kg. U	% U enrich	Kg. U-235	total Kg. Pu	Kg. Pu-239	SPM number
P7	CCT001	CastCrucTran	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	CAC001	CastCruc	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	931222102208CC	Binary	CastCharge	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	093-060-60086-00000
	MMB003	MkupMatlBCag	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	URC003	Uranium	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	931221151902	Uranium	MakeUp	5.3522	5.3522	0.1999	0.0107	0.0000	0.0000	093-060-60086-00000
	Total			18.5188	17.9766		0.0360	0.0000	0.0000	
P8	CMP001	CastMoldPall	Container	0.0000	0.0000	0.2101	0.0000	0.0000	0.0000	
	931221141431B	Glass	Molds	2.6515	0.0000	0.0000	0.0000	0.0000	0.0000	
	Total			2.6515	0.0000		0.0000	0.0000	0.0000	
	Total Transfers In			21.1703	17.9766		0.0360	0.0000	0.0000	

Transfers Out:

Source Zone	Item ID	Type	Form	Net Weight	total Kg. U	% U enrich	Kg. U-235	total Kg. Pu	Kg. Pu-239	SPM number
P7	CAC001	CastCruc	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	940111142228A	CastBinAlly	HeelPieces	5.5683	5.0102	0.2112	0.0106	0.0000	0.0000	
	MMB003	MkupMatlBCag	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	URC003	Uranium	Container	0.0016	0.0016	0.1999	0.0000	0.0000	0.0000	
	Total			5.5719	5.0138		0.0106	0.0000	0.0000	
P8	CMP001	CastMoldPall	Container	0.0000	0.0000	0.2101	0.0000	0.0000	0.0000	
	940111142228B	CastBinAlly	MoldedPin	17.0571	12.9620	0.2112	0.0274	0.0000	0.0000	093-060-60086-00000
	Total			17.0571	12.9620		0.0274	0.0000	0.0000	
	Total Transfers Out			22.6290	17.9758		0.0380	0.0000	0.0000	

Final Inventory:

Zone	Item ID	Type	Form	Net Weight	total Kg. U	% U enrich	Kg. U-235	total Kg. Pu	Kg. Pu-239	SPM number
P7	CCT001	CastCrucTran	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	FHC001	FissOuterHsg	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	LWC002	LowWrthFiss	Container	-0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	
	FHCX01	FissOuterHsg	Container	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	
	LWC001	LowWrthFiss	Container	-0.0007	0.0000	0.0000	0.0000	0.0000	0.0000	
	Total			-0.0008	0.0000		0.0000	0.0000	0.0000	
	Total Final Inventory			-0.0008	0.0000		0.0000	0.0000	0.0000	

Inventory Difference:

Zone	Item ID	Type	Form	Net Weight	total Kg. U	% U enrich	Kg. U-235	total Kg. Pu	Kg. Pu-239
	Inventory Difference			-0.0051	0.0008		-0.0020	0.0000	0.0000

Fig. 5. Material Balance Report (Edited) Written by MTG Task MCADAT

WE200A	1	1	1.70000	1.00000
WE200A	1	2	1.70000	1.00000
WE400A	1	1	2.33000	0.60000
WE400B	1	1	1.06000	1.37000
WE400C	1	1	4.08000	2.21000
OUTCELL	1	1	1.70000	1.00000
Mass_Spec	2	1	0.71000	0.01000
UNITY	1	0	0.00000	0.00000

Fig. 6. MAWST Measurement Error File for U-238

```
Scales: OUTCELL      1
OUTCELL
Scales: WE200A       1
WE200A
Scales: WE400A       1
WE400A
Scales: WE400B       1
WE400B
Scales: WE400C       1
WE400C
Composition:         1
Mass_Spec
Others               1
UNITY
```

Fig. 7. MAWST Measurement Methods File

```
*****************
MATERIALS BALANCE
*****************

UPA           bal 1
BALANCE NO.    1

 MATERIALS BALANCE  =    0.272176E+01
 STANDARD DEVIATION =    0.161446E+03
 LIMIT OF ERROR     =    0.322892E+03

CONTRIBUTIONS OF MEASUREMENT METHODS

     METHOD            CONTRIBUTION
 Scales: OUTCELL        0.164613E+02
 Scales: WE200A         0.313805E+01
 Scales: WE400A         0.244530E+02
 Scales: WE400B         0.241896E+01
 Scales: WE400C         0.000000E+00
 Composition:           0.260183E+05
 Others                 0.000000E+00
 REMAINDER              0.000000E+00

 VARIANCE OF MB         0.260648E+05
```

Fig. 8. MAWST Variance Report for U-238

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