CONF-910774--77

Paper to be presented at the INMM 32nd Annual Meeting, Institute of Nuclear Materials Management, July 28-31, 1991, New Orleans, LA.

ANL/CP--72412

DE91 017308

AUG 21 1991

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Y. Orechwa, C.H. Adams, and A.M. White

Reactor Analysis Division
Argonne National Laboratory
9700 S. Cass Avenue
Argonne, IL 60439
(708)972-4876

*Work supported by the U.S. Department of Energy, Nuclear Energy Programs under Contract W-31-109-ENG-38.

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Reactor Analysis Division
Argonne National Laboratory
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ABSTRACT

The Integral Fast Reactor (IFR) is a generic advanced liquid metal cooled reactor concept being developed at Argonne National Laboratory (ANL).[1] There are a number of technical features of the IFR which contribute to its potential as a next-generation reactor. These are associated with large safety margins with regard to off-normal events involving the heat transport system, and the use of metallic fuel which makes possible the utilization of innovative fuel cycle processes. The latter feature permits fuel cycle closure with compact, low-cost reprocessing facilities, collocated with the reactor plant. These primary features are being demonstrated in the facilities at ANL-West, utilizing Experimental Breeder Reactor II and the associated Fuel Cycle Facility (FCF) as an IFR prototype.

The demonstration of this IFR prototype includes the design and implementation of the Mass-Tracking System (MTG). In this system, data from the operations of the FCF, including weights and batch-process parameters, are collected and maintained by the MTG running on distributed workstations. The components of the MTG System include: (1) an Oracle database manager with a Fortran interface, (2) a set of MTG "Tasks" which collect, manipulate and report data, (3) a set of MTG "Terminal Sessions" which provide some interactive control of the Tasks, and (4) a set of servers which manage the Tasks and which provide the communications link between the MTG System and Operator Control Stations, which control process equipment and monitoring devices within the FCF.

INTRODUCTION

Throughout the nuclear age, the development of fast spectrum nuclear power reactors has been motivated by the promise of significant energy resource extension. The forecasts of rapid growth in the demand for electricity, an increase in the constraints on the use of fissile fuels, and a decrease in economically recoverable fissile uranium, had in earlier years, contributed to the perception of the need for rapid deployment of fast spectrum reactors. In the last decade, however, not only have the forecasts proven to be exaggerated, but also economic conditions together with adverse public perceptions of the safety of nuclear power have conspired to decrease dramatically the rate of growth of nuclear power. The need for resource extension, although currently not perceived as critical in the short run, is still seen as a necessary goal requiring a technical solution in the long run. It is in this context, taking into account current economic realities and public perceptions, that Argonne National Laboratory (ANL) is developing the Integral Fast Reactor (IFR) concept (See Fig. 1).

This concept takes into account the entire reactor system - reactor, fuel cycle, and waste processing - as a single entity. Central to the IFR is the metallic fuel. Its use results in a radically improved fuel cycle technology, and together with liquid metal cooling and a pool configuration for the primary reactor coolant system leads to substantially greater reactor safety margins, especially with regard to off-normal transients without scram.

The IFR concept, as described in Fig. 1 and being developed at ANL and to be demonstrated at EBR-II with its attendant fuel cycle facility, is a generic concept. The viability of this concept and its perceived economic and safety advantages do not preclude configurations other than the one of a collocated reactor with a fuel cycle facility. These aspects of deployment will be strongly dependent on economic and institutional constraints. Thus, it must be kept in mind that the concept is "integral" not only because of the physical proximity of the reactor and the fuel cycle, but also because of the use of metallic fuel. It is this fuel type which gives the unique and advantageous characteristics to every aspect of the system, from the performance of the reactor, to the compactness and simplicity of the reprocessing, fuel fabrication, and waste disposal systems. This paper will address some of the issues of mass tracking and materials accounting and the approaches for dealing with them in the generic IFR concept as it is to be demonstrated at ANL.

MATERIALS MANAGEMENT FEATURES OF THE IFR FUEL CYCLE

There are numerous features of the IFR concept which have an impact on materials management. For example, collocation of the reactor with a dedicated fuel cycle facility, although optional, minimizes fuel shipments and allows the whole facility to be considered as a single materials management unit. Moreover, the good neutron economy of the IFR reactor core allows the system to be fissile self sufficient. That is to say, other than the initial delivery of fissile material (even U-235 only), sufficient plutonium is bred to make further fissile makeup unnecessary. Minor design changes to the core, such as the inclusion of an axial blanket, will allow, if necessary, the breeding of excess plutonium for the startup of other reactors.

Another feature of the IFR metal fueled core is its sufficiently hard neutron spectrum for the self consumption of the transuranic elements in the closed fuel cycle combined with the unique feature of pyroprocessing wherein the chemistry of the process causes all transuranics to follow the plutonium product stream. In this way over 99.99% of all transuranics are recycled into the reactor core as fuel for in-situ burning.

Thus, the IFR features of collocation of reactor and dedicated fuel cycle, fissile selfsufficiency, and transuranic self consumption define the facility boundary as a natural control volume (see Fig. 2). After the first core loading, subsequent operation of the IFR will, in principle, require as additions to the facility only U-238 as fuel makeup, steel, and chemical reagents. The only waste stream materials to leave the facility boundary will consist of fission products, steel, and chemical reagents. The product stream is electrical power; with a concomitant waste heat rejection stream.

Another feature of the IFR fuel cycle which has an impact on special materials management is the fact that plutonium and uranium exist at every point in the fuel cycle as one chemical mixture. In addition, this mixture is extremely radioactive due to incomplete fission product separation. Thus, from the point- of-view of diversion resistance, the fissile material in the entire fuel cycle is always in a very unattractive form. The high radiation field associated with the fuel requires shielded remote operation of the entire fuel cycle and thereby adds a significant barrier especially to subnational diversion. Moreover, the unavoidable commixing of the plutonium with the minor actinides gives rise to strong neutron self emission which makes the material of low quality for potential military purposes.

The IFR fuel cycle is primarily a batch process, where the batch size which can be handled at each process equipment step is limited by criticality constraints. The fuel material is in the form of accountable items at each stage of the cycle, except in the electrorefiner. The simplicity of the process and the batch nature may allow for fewer measurements and more straight forward statistical methods to meet regulatory requirements.

MATERIALS MANAGEMENT DEVELOPMENT FOR THE IFR

The IFR concept is being developed at ANL with the objective of demonstrating all aspects of the complete cycle with the EBR-II reactor and the existing collocated but newly refurbished fuel cycle facility. The goal of this program is to demonstrate not only technical feasibility of the entire integrated cycle, but also commercial feasibility and economic viability. Although EBR-II is far from commercial size (~62MWe), the pyroprocessing and fuel manufacturing equipment to be installed at the fuel cycle facility will be near commercial size. Since material management performance is a strong function of throughput, demonstration of the fuel cycle operation at near commercial throughputs is critical. The batch nature of the IFR fuel cycle operation allows the accumulation of fuel from the EBR-II reactor and the subsequent processing of the accumulated material in short campaigns at near commercial throughput rates.

The demonstration with near commercial throughputs is being preceded with laboratory scale experiments for process development and subsequent operation of individual pieces of engineering scale equipment. These tests can serve as tools for building up a database for materials control and accounting. Data on sampling and measurement techniques and their uncertainties can be evaluated at this stage. Of particular importance are the REBUS/RCT[2] system of codes which predict the nuclear transmutations in the reactor core, and PYRO[3] which predicts the material partitioning in the electrorefiner. Computer codes such as these, if well validated, can reduce the sampling burden in the IFR system.

MASS TRACKING SYSTEM FOR THE IFR

While the main focus of the project is the hardware aspect of fuel-cycle technology, an integrated software system is also under development. In particular, Material Control and Accountability (MC&A) software is required to track fuel, feedstock and waste throughout the complete fuel cycle. Within the Fuel

Cycle Facility (FCF) the Mass-Tracking (MTG) System performs that function.

FCF COMPUTERS

Computers are used throughout EBR-II and FCF for a variety of functions. within FCF three levels of computers are integrated into the operations:

(1) Programmable Logic Controllers (PLCs) control much of the in-cell equipment. Because the FCF reprocesses spent fuel, essentially all of the operations are done remotely in a shielded cell.

(2) A set of Operator Control Stations (OCSs), in turn, control the PLCs. These are 386-based computers running Paragon software. They are the main interface between FCF operators and all FCF computers. They are equipped with keyboards and with touch screens.

(3) The MTG System resides on Unix workstations communicating with the OCSs. Although the MTG System does have some user interfaces (such as output to the MBA custodian), it receives most of its input from the OCSs, and sends most of its output to the OCSs to be displayed for the benefits of the operators.

MTG SYSTEM ARCHITECTURE

The MTG System has a modular architecture (see Figure 3) consisting of a variety of processes. These can be categorized into three basic groups.

(1) MTG Tasks. These are processes which (1) model fuel processing steps (e.g. fuel pin casting), (2) model other, physical processes (e.g. radioactive decay), and (3) serve administrative functions (e.g. confirm compliance with criticality-safety rules). At any one time several MTG Tasks may be running simultaneously, servicing requests from different OCSs, and it is possible that several copies of a single Task may be running simultaneously.

(2) MTG Terminal Sessions. These are programs which provide terminal interfaces to users, most likely process engineers, for input and output not provided through the OCSs. Terminal Sessions, for example, will manage shutdown and startup of the MTG System itself, will respond to simple queries about the location of items within the FCF, and ultimately will provide the tools necessary for planning day-to-day operations. The screen displays for MTG Terminal Sessions will be much simpler than those on OCSs since their users will be logging into the Unix workstations

from a variety of types of terminals.

(3) Servers. These are a few processes running continuously and concurrently which (1) manage communications between the OCS and the MTG System, (2) manage communications between the Terminal Sessions and particular MTG Tasks, (3) retrieve information from the MTG System for users on remote hosts, and (4) manage the execution of MTG Tasks.

The database which is at the heart of the MTG System is managed by a copy of the Oracle Relational Database Manager. All containers and process material are treated as accountable items in the database and are tracked in both time and location. composition data for items are stored in sequential files outside of Oracle, but the file names are in the database.

Communications between processes are handled with a combination of network messages and files. Messages are sent between the Servers and Tasks when Tasks start and terminate; most of the required data are passed in files.

MATERIAL ACCOUNTING FOR THE IFR

The material accounting and variance propagation for the fuel cycle facility will be performed with the MAWST computer code.[4] This code interfaces with the MTG system through the code MAMI as shown in Fig. 4. The MTG system is the source for the dynamic information, such as mass flows and inventories, needed for inventory difference calculations. Less dynamic information, such as that associated with measurement error and methods, can of course also be stored in the MTG system.

Since the MTG system is currently under development, prior to the availability of the completed process equipment at the FCF, a computer code, SIMIFR[5] has been written for simulating the mass flows throughout the IFR. SIMIFR produces simulated data files in the proper MTG format input files for analysis by MAWST. This allows an a priori analysis of the IFR material accountancy to be made (parametric in assumed sampling and measurement errors) for evaluating the precision required to meet regulatory standards and for conducting diversion vulnerability scenario assessments.

During startup and the initial phase of operation of the FCF, the material accounting system will be required to assure conformance with regulations at each step as the system and equipment pass through the different stages of testing and demonstration. As facility operation evolves from operation with depleted uranium, to nonrecycled fuel feed, and finally to irradiated fuel feed, the material accounting requirements are going to change. Simulation will significantly aid in projecting the design requirements to meet this evolution.

CONCLUSION

The IFR program is in the process of developing a concept which includes not only a new fuel, but also an innovative fuel cycle and waste management strategy. The goal is to demonstrate the commercial feasibility of the IFR as a safe and economical source of electric power. A component of the commercial viability of the IFR is a mass tracking and material accounting system which can demonstrably meet requirements for future broad-scale deployment. The many unique features, of the IFR are being exploited by the material management system under development. In addition, the simultaneous development of both the technical processes and the operating equipment together with the materials management system allow the latter to be designed as a symbiotic part rather than an add on to an existing system.

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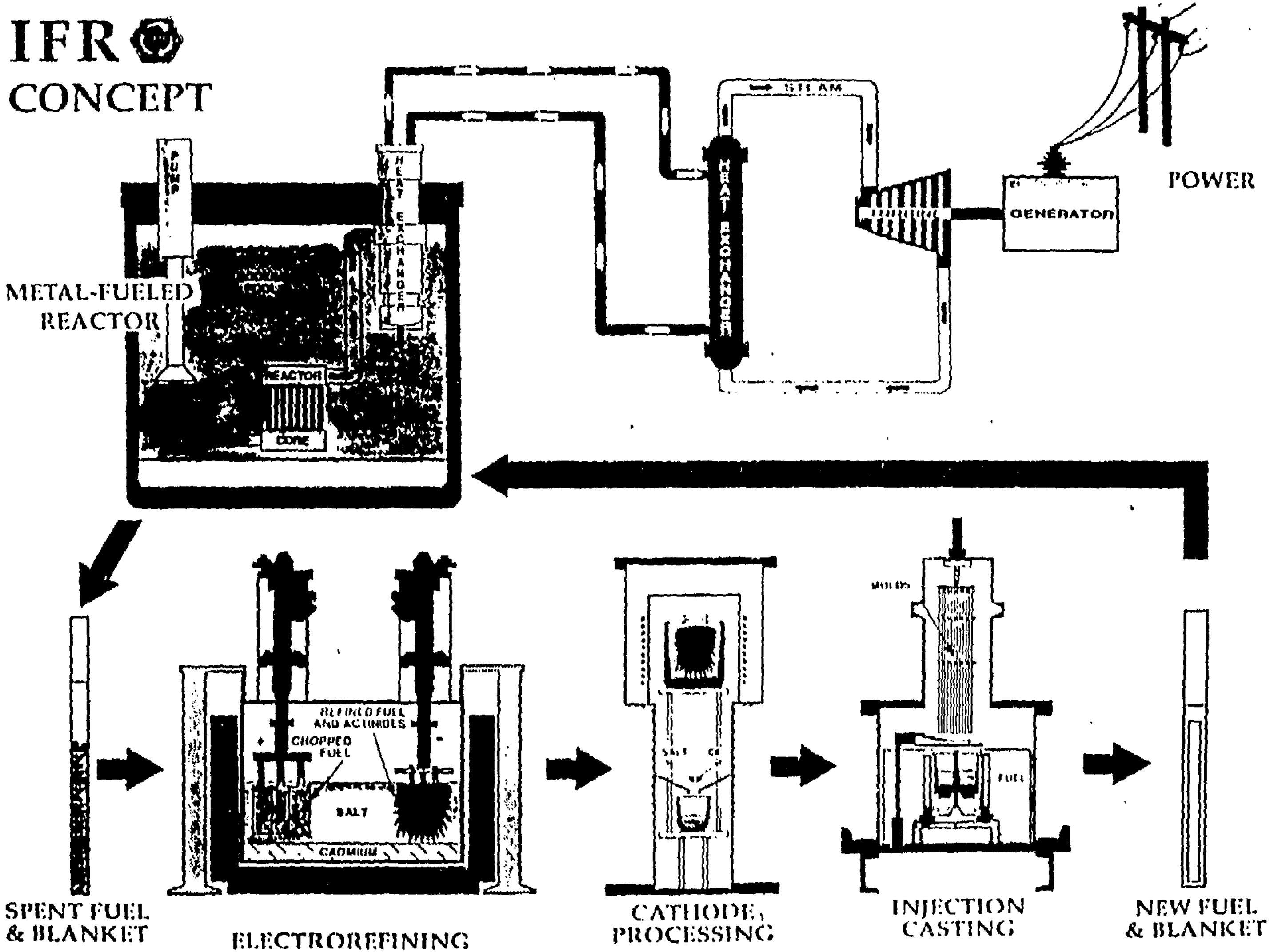

Fig. 1 Main Process Elements of the IFR Concept

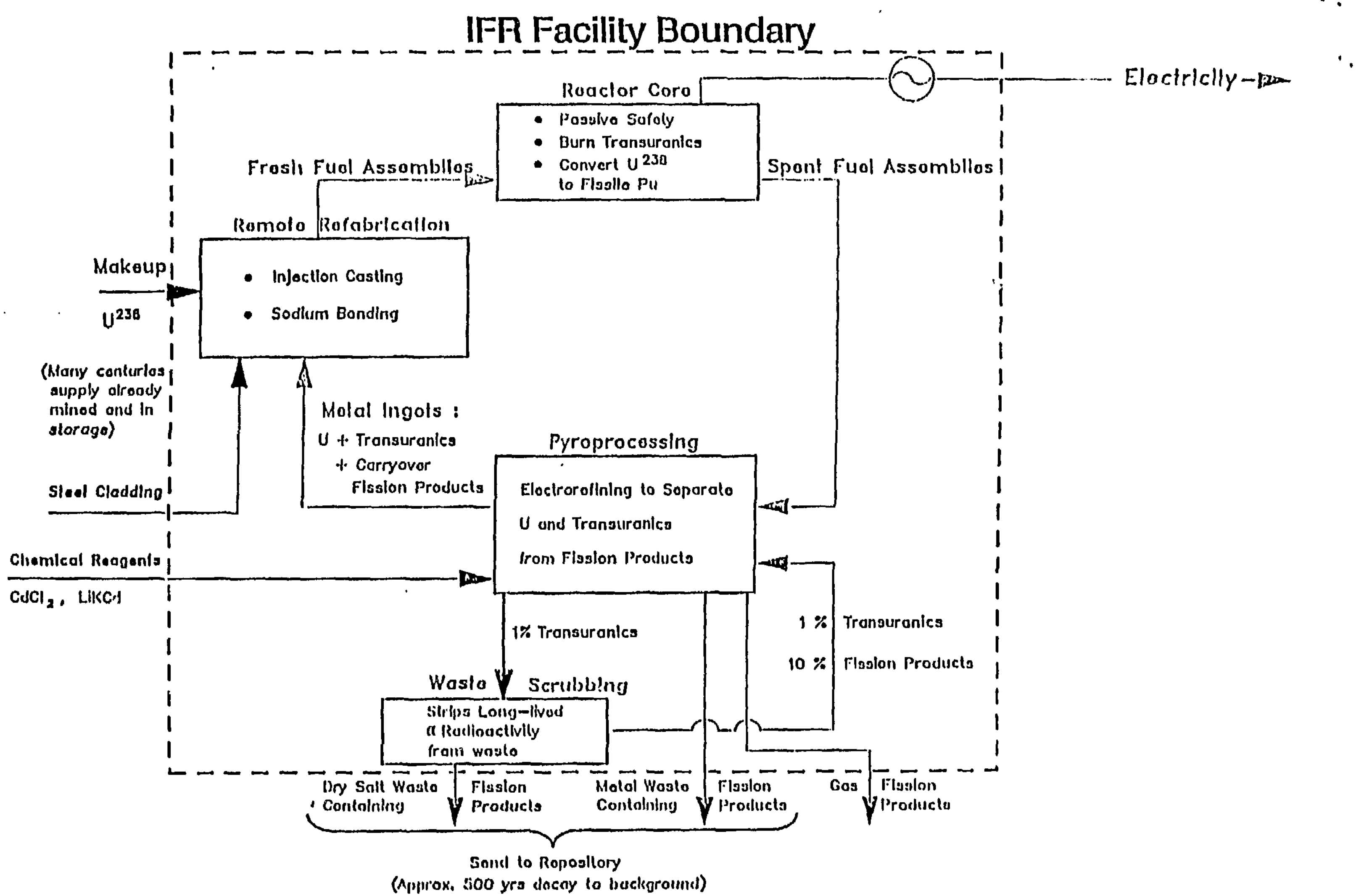

Fig. 2 Material Flows in the Generic IFR Concept

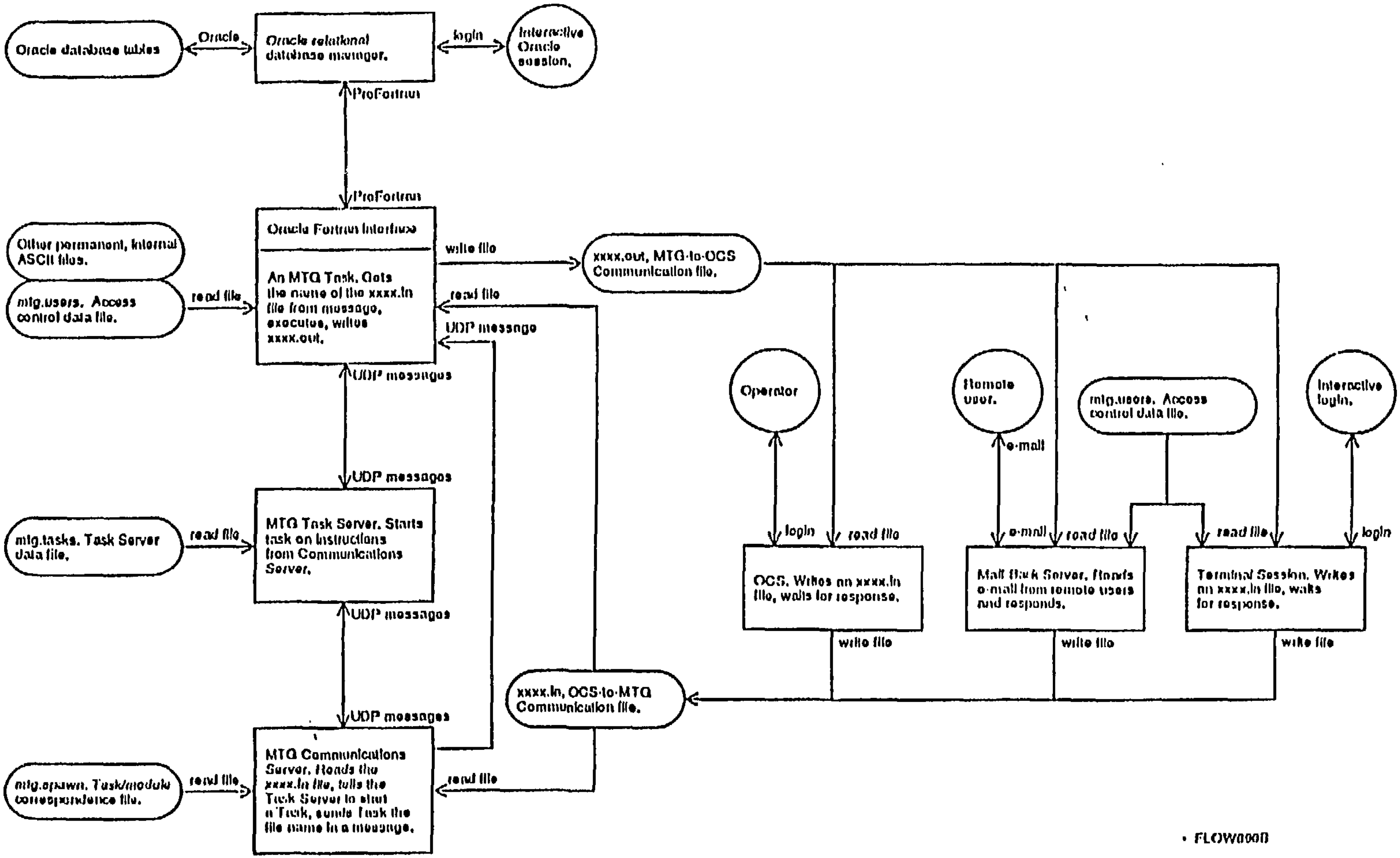

Figure 3: A schematic diagram of the processes comprising the MTG System. Boxes indicate MTG Tasks, Terminal Sessions and Servers. Obrounds indicate files, and circles show points of access by users.

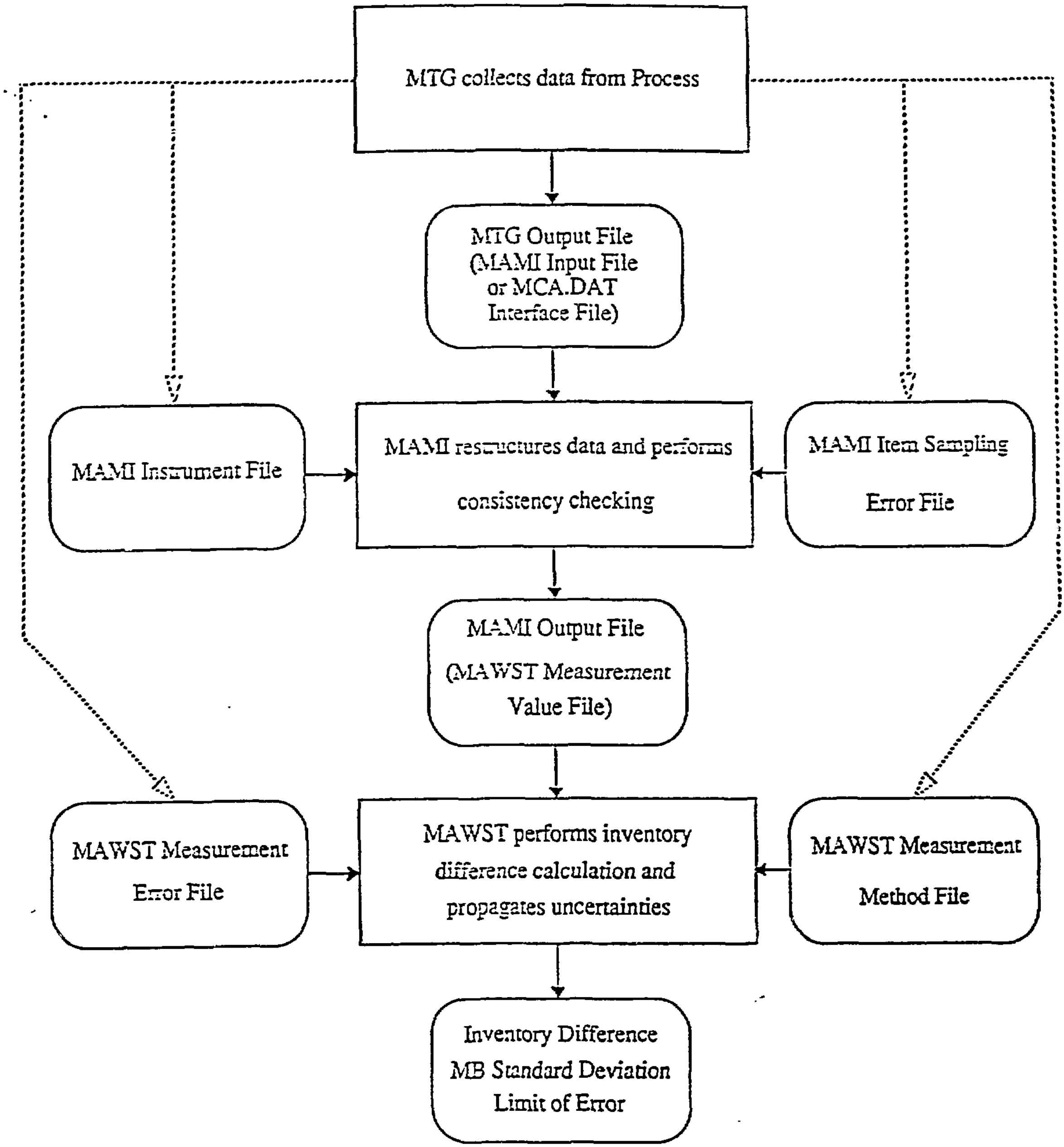

Fig. 4 Data Flow from the Mass Tracking (MTG) System to the Material Accounting System