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# THE CASSINI PROJECT: LESSONS LEARNED THROUGH OPERATIONS



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**Abstract**

The Cassini space probe requires 180 $^{238}$Pu Light-weight Radioisotopic Heater Units (LWRHU) and 216 $^{238}$Pu General Purpose Heat Source (GPHS) pellets. Additional LWRHU and GPHS pellets required for non-destructive (NDA) and destructive assay purposes were fabricated bringing the original pellet requirement to 224 LWRHU and 252 GPHS. Due to rejection of pellets resulting from chemical impurities in the fuel and/or failure to meet dimensional specifications a total of 320 GPHS pellets were fabricated for the mission. Initial plans called for LANL to process a total of 30 kg of oxide powder for pressing into monolithic ceramic pellets. The original 30 kg commitment was processed within the time frame allotted; an additional 8 kg were required to replace fuel lost due to failure to meet Quality Assurance specifications for impurities and dimensions. During the time frame allotted for pellet production, operations were impacted by equipment failure, unacceptable fuel impurities levels, and periods of extended down time, >30 working days during which little or no processing occurred. Throughout the production process, the reality of operations requirements varied from the theory upon which production schedules were based.

## INTRODUCTION

The Cassini space probe is scheduled to be launched from Cape Canaveral to Saturn in October 1997 and reach Saturn in July 2004. The mission is a joint effort between NASA, the European Space Agency, the Italian Space Agency, and several United States national laboratory facilities all under the guidance of the Jet Propulsion Laboratory.

The Cassini probe itself will orbit Saturn for four years. A separate probe, Huygens, will be deployed from Cassini to land on Titan, Saturn's largest moon. Cassini will serve as an information relay station for the Huygens probe as well as transmitting information it gathers back to Earth as it orbits the planet. LANL has several divisions actively supporting the mission, with group NMT-9 of LANL's Nuclear Materials and Technology Division providing oxide powder processing, fuel pelletization and encapsulation, and safety testing services. The following report examines issues associated with oxide powder processing that were not fully appreciated when the production schedule for Cassini fuel was created. That schedule called for limited initial processing operations to commence in January 1994, a ramp up to full scale production in April 1994, and completion in December 1995; the last pellet for the flight was pressed and encapsulated in September 1996.

## PROGRAMMATIC PROCESSING REQUIREMENTS

TABLE 1 TARGET VERSUS ACTUAL FUEL PROCESSING RESULTS

| Months/Yr | Target 238 Process (kg)/Month | Actual 238 Process (kg)/ Month | Target Pellets Pressed/Month | Actual Pellets Pressed/Month |
|---|---|---|---|---|
| Jan 94 - Nov 95 | ≈1.6 kg | ≈1.2 | 10 | ≈10 |
| Dec 95 - Sep 96 | 0 | ≈1.1 | 3 | 9 |
| Totals, Jan 94 - Sep 96 | 38 (kg) | 38.6 (kg) | 252 pellets | 315 pellets |

As noted in TABLE 1, the production goal was set at roughly 1.6 kg per month. The zero in the "Dec 95 - Sep 96" is indicative of the target schedule calling for all oxide powder production to be completed by that time. As noted,

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actual production occurred for the next ten months at the rate of roughly 1.1 kg/month. The discrepancy between actual and target processing rates resulted from time being required for routine glovebox maintenance activities and addressing administrative issues.

## PROCESS EQUIPMENT

For each oxide powder fuel lot, the initial processing step, $O^{16}$ exchange and the final processing step, granule seasoning, constitute the longest duration processing operations. Two other operating steps, ball milling and cold pressing/slugging and screening fuel lots, were conducted simultaneously with furnace operation. Ideally, as a fuel lot completed slugging and screening, furnaces would be available for granule seasoning (sintering).

TABLE 2 OXIDE POWDER FUEL PROCESSING SEQUENCE AND DURATION

| Operation | Duration (hours) |
|---|---|
| Fuel Introduction to Glovebox System | 2 |
| $O^{16}$ Exchange | 47 |
| Ball Milling | 9 |
| Manual Slugging and Screening | 2 |
| Granule Seasoning | 23 - 27 |

The original processing scheme revolved around the availability of nine process furnaces to be used for oxide powder $O^{16}$ exchange, granule seasoning and pellet sintering operations. The primary equipment used for the Cassini project consisted of three Centorr furnaces (maximum operating temperature ≈ 1250°C) and six Astro Industries furnaces (maximum operating temperature ≈ 1750°C). The fuel lots were processed to maintain a low-fired/high-fired ratio of 60:40; the ratio required to produce a pellet which would press into the desired shape and density and not be prone to fracture. Low fired and high fired fuels are sintered at 1100°C and 1600°C, respectively. With the average fuel lot weighing 181g net, the failure of a single furnace impacted the production flow of more than one fuel lot. (see TABLE 3.) Fuel lots were processed in a manner that, following splitting to accommodate furnace capacities, allowed all portions of the lot to move through the processing sequence simultaneously; partial lots did not advance to the next processing stage.

TABLE 3 **Furnace Capacity and Function**

| Furnace Group ID | Pt Boat Maximum Capacity | Process Capabilities |
|---|---|---|
| Centorrs 1, 2, &3 | 150 grams | O16 Exchange, Low Fired Granule Seasoning |
| Astro 1 | 2 GPHS pellets or 16 LWRHU pellets | Dedicated to pellet sintering |
| Astros 2 & 3 | 50 grams | O16 Exchange, Low and High Fired Granule Seasoning |
| Astros 4, 5, & 6 | 90 grams | O16 Exchange, Low and High Fired Granule Seasoning |

The furnaces with their original control consoles and hardware were installed at TA-55 circa 1980 following their removal from operations at LANL's old plutonium processing facility. Prior to Cassini operations, some upgrade of components (chart recorders, program controllers) was performed but the original power supply components and controls were not altered.

As operations ramped up in support of the Cassini project, the furnaces were subjected to increased utilization and a subsequent increase in furnace down-time as aged component failure accelerated. Replacement graphite heating elements, alumina core tubes, and thermocouple components had been previously manufactured and/or stockpiled; maintaining an inventory of all power supply components was not practical. Replacing a core tube removed a furnace from service for two working days, heating element replacement required four to five working days, and thermocouple replacement required one day. Thermocouples presented a problem as they were fragile, subject to breaking from slight impacts with other objects, and each furnace required a thermocouple manufactured to a specific length. Thermocouples also had to be replaced as a result of heating element replacement; the primary heat zone generated by each element would shift the position of the thermocouple sensing tip. Any furnace repair work also meant removing a fuel processing operator from processing activity, assigning that operator to effect the repair.

With increasing frequency, electronic control components began to fail. For several of the furnaces, the failed components were no longer manufactured and locating a replacement often proved to be difficult or fruitless. Eventually, a furnace would be declared inoperable and its functional components cannibalized for use in other furnace control systems.

Additionally, processing activities were adversely impacted as a result of combinations of fuel impurities, maintenance requirements, equipment failure and addressing administrative issues not anticipated when the production schedule for Cassini was determined.

## FUEL IMPURITIES

Throughout the project, fuel impurities issues would impact our ability to create an acceptable finished product. Impurity levels were determined using spectrographic quantification methods by another LANL Division. (Impurities tracked for the Cassini Project: Al, B, Be, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Mo, Na, Ni, P, Pb, Si, Sn, Zn.) Discovering the extent of impurities occurred only after fuel had completed oxide powder processing and hot press operations. In general, the fuel and sample flow scheme followed the pattern shown in TABLE 4.

TABLE 4 TYPICAL OXIDE POWDER FUEL PROCESSING/SAMPLING FLOW PATTERN

| Day 1* | Day 5 | Day 6 | Day 8 | Day 12 | Days 15 - 30 | Days 20 - 45 |
|---|---|---|---|---|---|---|
| Fuel introduced to glovebox system, analytical sample (S1) obtained | | | | | | |
| | Oxide powder processing complete,analytical sample (S3) obtained | | | | | |
| | | Monolithic pellet pressed | | | | |
| | | | **S1** shipped off-site for analysis | | | |
| | | | | **S3** shipped off-site for analysis | | |
| | | | | | **S1** results reported | |
| | | | | | Pellet pressed | |
| | | | | | | **S3** results reported |

* Days are operator workdays, not necessarily consecutive calendar days

Following introduction into the glovebox system, the fuel was poured from its shipping container into a weighing pan and sampled for impurities analysis using a "grab" method; potentially missing agglomerations of impurities within the body of the fuel. Due to the time lag between sample acquisition and results reporting fuel was processed through the granule seasoning stage. Initial (S1) sample results might indicate fuel acceptable for use in pelletization while the subsequent S3 might contradict those results; S3 samples served as the determinant of fuel acceptability. It is possible that the fuel became homogenous during several sieving and particle size adjustment steps; the agglomerations being broken apart and blended throughout the fuel lot. Pellets with lots too high in impurities, but pressed prior to receipt of S3 results, were recovered for reprocessing as scrap material a total of 40 pellets were scrapped for this reason. In addition, operator radiation exposure approaching ALARA limits were incurred while processing unusable fuel.

## The October Push

In October 1995 an agreement was struck between NMT-9 and the shipping and analytical groups to provide ten day turnaround on samples from 25 fuel lots. The 25 lots were introduced into the glovebox system over the course of two consecutive weeks. As the lots were introduced, the S1 samples would be obtained, the fuel processed through O16 exchange then stored in line until analytical results were reported. Material having unacceptable impurity levels followed one of two paths. They were scrapped (several lots being rejected outright) prior to extensive processing or, as part of the pelletization process, a blend of lots would be created resulting in a pellet with acceptable impurities levels. Operator exposure was now incurred for processing fuel that was usable on a stand alone basis or as a blend but at the same time, background exposure increased due to the volume of material stored throughout the processing area.

## ROLLING STAND-DOWNS

### January 1995

The first rolling stand-down began in January 1995. During this stand-down, processing operations were allowed to continue; they were slowed due to restrictions imposed by the stand-down. The restrictions included the erection of a contamination containment system required for use during window change operations following the discovery that window seal gaskets in two gloveboxes were badly decomposed.

TABLE 5 SUMMARY of CONTAMINATION and CAM ALARM EVENTS LEADING to OPERATIONS STAND-DOWN

| Reporting Period | Number of Reportable Events (Contamination or CAM alarm) | Average Number of Reportable CAM or Contamination Events/Month |
|---|---|---|
| **September 1994 - January 1996** | **59** | **3.7** |
| September 1994 - January 1995 | 17 | 3.4 |
| July 1995 - January 1996 | 32 | 6.4 |
| September 1995 - January 1996 | 14 | 2.8 |

It was determined that the gaskets were the likely cause of several previously unexplained CAM alarms. As derived from TABLE 5, the events for the five months from September 1994 to January 1995 accounted for 28.8 per cent of all the events in a 17 month period.

Replacing the seals required replacing the window the seal held in place. As part of the solution for alleviating the problem, use of a new, to LANL, window change glove bag contamination containment system was mandated. The system incorporates a clear vinyl bag equipped with ports for attaching glovebox gloves, downdraft HEPA apparatus and replacement parts. The bag walls and ports are created by laminating separate pieces together. The bags are attached to the glovebox face by means of a series of layers of tape. A crease or bubble in any layer creates a starting point from which a breach may emerge. The weight of the bag is borne by a suspension system that tends to pull the bag away from the glovebox face leading to increased stress on the tape seals.

The training and set-up for changing the first window took approximately two weeks. For all subsequent windows, it was never less than three work days from the time containment bag installation was initiated until the window and gasket were replaced and room decontamination completed. In the following four weeks six more windows were changed including one that had been discovered to be failing on a third glovebox. That window was changed twice due to the replacement seal cracking under the stress of installation and ultimately being of no more value that the one it had replaced.

During three window changes, the containment bag system developed leaks to the room, either through the tape system used to attach the bag to the glovebox face or in the seams created when the plastic panels used to create the bag were laminated to form a joint between pieces. Subsequently, two or more days were spent decontaminating the room following those window changes.

### January 1996

The second, and more damaging to the processing schedule, stand-down began in late January 1996 and ended in mid-April 1996. The stand-down was precipitated by an increase in personnel contamination and Continuous Air Monitor (CAM) alarm incidents (refer to TABLE 5).

This stand-down enhanced awareness of the rules of formality of operations and provided an opportunity in which to thoroughly examine/test all glovebox penetrations for seal integrity. As part of this program, we agreed to change one glovebox (GB224) window that had developed a crack.

The GB224 window change was conducted in accordance with the current Safe Operating Procedure and employing a window change containment bag. However, when the plates holding the window in place on the glovebox were removed, the window dropped from its position, a hole developed in the containment bag seals, and the room became contaminated. The replacement window was installed as rapidly as practical but a five day period of room decontamination followed. It was determined that while we had maximum glovebox negativity, we did not have maximum airflow into the box from the room (possibly the result of an overpowering HEPA vacuum used for this operation) and the grease originally used to help seal the original gasket had dried up, leaving no tension source between the gasket and the glovebox face.

## Conclusions and Outcomes

A homogenization step (such as ball milling) should occur prior to obtaining initial fuel samples. This would increase the chances that the S1 sample would be replicated by the S3 sample. In turn, contributions to increased operator exposure levels with no commensurate final product output would be reduced. In conjunction with this, an improvement in analysis turnaround must be achieved. Current practices of one off-site shipment per week are not adequate for a large scale processing campaign. An analytical program dedicated to fuel analysis should be developed that will improve the time required for reporting impurities results.

Aged equipment should be avoided or some means for insuring the availability of all components should be developed prior to a large scale processing campaign. Failing that, the production schedule should recognize equipment age and make realistic allowances for equipment maintenance requirements. Where possible, furnace construction should allow for rapid replacement of component parts that do not alter the location of the primary heat zone. Thermocouples for these furnaces should be available "off the shelf" and capable of functioning within a sturdy sheath.

**TABLE 6 SUMMARY of CONTAMINATION and CAM ALARM EVENTS FOLLOWING OPERATIONS STAND-DOWN**

| Reporting Period | Number of Reportable Events (Contamination or CAM alarm) | Average Number of Reportable CAM or Contamination Events/Month |
|---|---|---|
| January 1995 - July 1995 | 10 | 1.4 |
| April 1996 - June 1997 | 22 | 1.5 |

As noted in Table 6, a significant reduction in average monthly CAM and/or contamination events followed each stand-down. The more rigorous the stand-down, the greater the time span over which a reduced number of events is recognized. Routine operations such as glove changes were examined for ways in which they could be improved. Operators were observed and the technique of the most successful operators (least contamination problems following glove changes) was adopted for use and all 238Pu Oxide Process personnel trained and certified to that technique. Use of downdraft HEPA vacuums was initiated as a means to keep material that might "puff" from beneath a glove cuff during removal from becoming airborne resulting in room and personnel contamination. Planning for a large scale processing campaign, should have as a component a thorough stand-down type operation in which potential problems and training requirements are identified and allowances made.

The window change containment bag is a good concept, however, its reliability is questionable. An improvement in the method for mounting the bags to the glovebox face, fewer heat sealed welds, and a better support system for the bags need to be developed.

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----------------------------------------------------NOMENCLATURE----------------------------------------------------

ALARA: As Low As Reasonably Achievable
HEPA filter: High Efficiency Particulate and Aerosol filter
$O^{16}$ Exchange: a process during which O16 replaces the O17 &18 isotopes in the fuel, leading to a reduction of neutron activity within the fuel lot
LANL: Los Alamos National Laboratory
TA-55: LANL Plutonium Processing facility