Materials Inventory Database for the Light Water Reactor Sustainability Program

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August 2013

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ABSTRACT

Scientific research involves the purchasing, processing, characterization, and fabrication of many sample materials. The history of such materials can become complicated over their lifetime – materials might be cut into pieces or moved to various storage locations, for example. A database with built-in functions to track these kinds of processes facilitates well-organized research. The Material Inventory Database Accounting System (MIDAS) is an easy-to-use tracking and reference system for such items.

The Light Water Reactor Sustainability Program (LWRS), which seeks to advance the long-term reliability and productivity of existing nuclear reactors in the United States through multiple research pathways, proposed MIDAS as an efficient way to organize and track all items used in its research. The database software ensures traceability of all items used in research using built-in functions which can emulate actions on tracked items – fabrication, processing, splitting, and more – by performing operations on the data. MIDAS can recover and display the complete history of any item as a simple report.

To ensure the database functions suitably for the organization of research, it was developed alongside a specific experiment to test accident tolerant nuclear fuel cladding under the LWRS Advanced Light Water Reactor Nuclear Fuels Pathway. MIDAS kept track of materials used in this experiment from receipt at the laboratory through all processes, test conduct and, ultimately, post-test analysis. By the end of this process, the database proved to be right tool for this program. The database software will help LWRS more efficiently conduct research experiments, from simple characterization tests to in-reactor experiments. Furthermore, MIDAS is a universal tool that any other research team could use to organize their material inventory.
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1. INTRODUCTION

Nuclear power accounts for about 20 percent of electrical power generation in the United States. As demand for electrical energy grows, advancing the long-term reliability and productivity of existing nuclear reactors is an economical way to meet energy needs. The Light Water Reactor Sustainability (LWRS) Program aims to extend nuclear power plant operating life in the U.S. with multiple research pathways in order to address this goal.\textsuperscript{1} This project is part of the Advanced Light Water Reactor Nuclear Fuels Pathway within the LWRS program, which seeks to improve knowledge about nuclear fuel and cladding performance. With this research, LWRS will develop improved fuel and cladding designs for existing nuclear reactors.

Nuclear fuel performance research – and scientific research in general – involves the purchasing, processing, characterization, and fabrication of many sample materials and fabricated components. LWRS proposed creating the Material Inventory Database Accounting System (MIDAS) as a tracking and reference system for such materials used in its research. During development, the database software must demonstrate its value by tracking items used in an experiment under LWRS. MIDAS should ensure traceability of all items used in research, and streamline organization of the program’s research inventory.

2. INITIAL DATABASE DESIGN

MIDAS is a Microsoft Access database with supporting code written in Visual Basic for Applications (VBA). Individual parts are listed as rows, known as records, and information about each part is listed in columns, known as fields. Microsoft Access is a better organizational tool than Microsoft Excel for this kind of information for a few reasons. Access has built-in cross-table reference functionality, so it is easy to keep supporting information in separate tables, referencing them when necessary. Access also supports attachments, so documents such as
material certification and analysis reports can be directly referenced in the database. Most importantly, VBA code allows for automation of repetitive database management tasks.

All items tracked by MIDAS start in the Raw Materials table. It contains important information about the material such as serial and lot numbers, the supplier, date received, as well as a description of the material. This is intended to be just an organizational tool for material procurement, listing items as they are purchased (Figure 1). Before any actions are performed on these materials, they must be imported into the Material Inventory table, which is the heart of the database. This table lists descriptive information about items, such as size, quality level, processing performed, etc. (Figure 2). These tables reference supporting information in other tables, such as personnel contact information, storage locations, statements of work, etc.

Figure 1: An excerpt from the raw materials table

<table>
<thead>
<tr>
<th>ID</th>
<th>Lot Number</th>
<th>Serial Number</th>
<th>Description</th>
<th>Material Type</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Various 2200200x</td>
<td>2200100x</td>
<td>Spool; &lt;150 m</td>
<td>HI-NICALON type S</td>
<td>PSI</td>
</tr>
<tr>
<td>2</td>
<td>482220</td>
<td>22002001</td>
<td>Spool</td>
<td>HI-NICALON type S</td>
<td>PSI</td>
</tr>
<tr>
<td>3</td>
<td>482220</td>
<td>22002003</td>
<td>Spool</td>
<td>HI-NICALON type S</td>
<td>PSI</td>
</tr>
<tr>
<td>4</td>
<td>4911237</td>
<td>22002004</td>
<td>Spool; &lt;150 m</td>
<td>HI-NICALON type S</td>
<td>PSI</td>
</tr>
<tr>
<td>5</td>
<td>496223</td>
<td>23010303</td>
<td>Spool; 550 m</td>
<td>HI-NICALON type S</td>
<td>PSI</td>
</tr>
<tr>
<td>6</td>
<td>4911237</td>
<td>22090105</td>
<td>Spool; 550 m</td>
<td>HI-NICALON type S</td>
<td>PSI</td>
</tr>
<tr>
<td>7</td>
<td>4911237</td>
<td>22090106</td>
<td>Spool; 550 m</td>
<td>HI-NICALON type S</td>
<td>PSI</td>
</tr>
<tr>
<td>8</td>
<td>496223</td>
<td>23010301</td>
<td>Spool; 550 m</td>
<td>HI-NICALON type S</td>
<td>PSI</td>
</tr>
<tr>
<td>9</td>
<td>496223</td>
<td>23010302</td>
<td>Spool; 550 m</td>
<td>HI-NICALON type S</td>
<td>PSI</td>
</tr>
<tr>
<td>10</td>
<td>4911237</td>
<td>22090104</td>
<td>Spool; 550 m</td>
<td>HI-NICALON type S</td>
<td>PSI</td>
</tr>
</tbody>
</table>

Figure 2: An excerpt from the material inventory table

<table>
<thead>
<tr>
<th>ID</th>
<th>LWRIS ID</th>
<th>Date</th>
<th>Type</th>
<th>Raw Source</th>
<th>Description</th>
<th>weight / length</th>
</tr>
</thead>
<tbody>
<tr>
<td>376</td>
<td>LWRIS-0071</td>
<td>5/20/2013</td>
<td>Consumed 11-135</td>
<td>Watlow resistance heater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>377</td>
<td>LWRIS-0072</td>
<td>5/20/2013</td>
<td>Partly Consumed WSHA71 53-3</td>
<td>Zn4 tube; 12&quot; Length</td>
<td></td>
<td></td>
</tr>
<tr>
<td>378</td>
<td>LWRIS-0072-C01</td>
<td>5/20/2013</td>
<td>Consumed WSHA71 53-3</td>
<td>2&quot; tube, Sic 11</td>
<td>2&quot;</td>
<td></td>
</tr>
<tr>
<td>379</td>
<td>LWRIS-0072-C02</td>
<td>5/20/2013</td>
<td>Consumed WSHA71 53-3</td>
<td>2&quot; tube, Sic 10</td>
<td>2&quot;</td>
<td></td>
</tr>
<tr>
<td>380</td>
<td>LWRIS-0072-C03</td>
<td>5/20/2013</td>
<td>Consumed WSHA71 53-3</td>
<td>2&quot; tube, Sic 12</td>
<td>2&quot;</td>
<td></td>
</tr>
<tr>
<td>381</td>
<td>LWRIS-0073</td>
<td>5/20/2013</td>
<td>Consumed EC-14</td>
<td>End Caps</td>
<td>6&quot;</td>
<td></td>
</tr>
<tr>
<td>382</td>
<td>LWRIS-0074</td>
<td>5/20/2013</td>
<td>Consumed 10-480</td>
<td>Sic, 2ply 7 cycle</td>
<td>6&quot;</td>
<td></td>
</tr>
<tr>
<td>383</td>
<td>LWRIS-0075</td>
<td>5/20/2013</td>
<td>Consumed 10-480</td>
<td>Sic, 1ply 7 cycle</td>
<td>6&quot;</td>
<td></td>
</tr>
<tr>
<td>384</td>
<td>LWRIS-0069-P</td>
<td>5/20/2013</td>
<td>Consumed 11-135</td>
<td>Modified heater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>385</td>
<td>LWRIS-0070-P</td>
<td>5/20/2013</td>
<td>Consumed 11-135</td>
<td>Modified heater</td>
<td></td>
<td></td>
</tr>
<tr>
<td>386</td>
<td>LWRIS-0071-P</td>
<td>5/20/2013</td>
<td>Consumed 11-135</td>
<td>Modified heater</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
2.1 The ID System

As items undergo changes during research, these changes should be reflected in the database. Database management is time consuming, so MIDAS has a set of VBA functions to perform these changes with minimal user input. MIDAS generates a unique ID for each item imported to the Material Inventory table. When executed, the VBA functions emulate actions taken on a given tracked item – fabrication, processing, cutting, and more – by creating a new record with a modified ID based on the original item ID. Rather than modify the existing record, these functions create a new record in order to maintain the complete history of tracked items. This new ID is marked with a suffix to indicate what led to its generation (Table 1). This system allows the user to understand the history of an item just by looking at its ID; MIDAS also relies on these IDs to determine how it should alter records when its functions are called.

<table>
<thead>
<tr>
<th>Action</th>
<th>Description</th>
<th>Suffix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut</td>
<td>A material is divided into pieces</td>
<td>-Cxx</td>
</tr>
<tr>
<td>Process</td>
<td>A process is applied to a material, changing it physically</td>
<td>-P</td>
</tr>
<tr>
<td>Fabricate</td>
<td>Items are combined together to create a new assembly</td>
<td>-F</td>
</tr>
<tr>
<td>Recover</td>
<td>A fabricated item is disassembled, yielding its components</td>
<td>-R</td>
</tr>
</tbody>
</table>

Take an example item which is imported to the Material Inventory table with the ID “Item-0015”. This part is then cut into three pieces – invoking the cut control yields three new records, the third of which would be “Item-0015-C03”. Information about cut dimensions is stored in a separate field. If this item is then processed, another record is created called “Item-0015-C03-P”. The specific type of process is not specified in the ID, but in a separate field. While records and their IDs can be changed manually, it is better to let the VBA code handle the ID system to ensure consistency and code functionality.
2.2 The User Interface

Each table in Microsoft Access has a corresponding window where the user can view or change information for one record at a time. Most of the time spent using MIDAS will be in the Material Inventory window, which displays part information and allows the user to call any of the built-in functions available (Figure 3). Cutting and processing materials is simple, as shown in Figure 4 on the next page. The program asks for some information in a new window, then creates new records and populates them automatically. Fabricating and disassembling materials is more complicated and will be explained in more detail.

![Material Inventory](image)

Figure 3: The Material Inventory window
The Fabricate command is used when multiple items are used to assemble a new material. Any number of items can be selected for this process (Figure 5). In this example, a new record will be created with the name “LWRS-0078-F”. This single ID cannot reflect every single part used in the fabrication of the item, so the list of these parts is stored in a separate field.

The database software was initially developed according to this overall design, but without the ability to disassemble
fabricated items, and lacking information and functionality to make viewing and understanding the history of a part a simple process. Testing the ability of the database to track materials used in an actual experiment revealed what features the database lacked and what changes needed to be made. This methodology helps ensure the database is suitable for tracking scientific research.

3. TESTNG AND DEVELOPING THE DATABASE

3.1 The Experiment

MIDAS was tested by tracking materials through the fabrication process for a specific experiment. The LWRS Advanced Light Water Reactor Nuclear Fuels Pathway is investigating the use of Silicon-Carbide Ceramic Matrix Composites (SiC-CMC) as a more accident-tolerant nuclear fuel cladding material. The potential advantages of SiC cladding include increased corrosion resistance and reduced hydrogen generation during accident conditions when the cladding is exposed to steam.\(^2\) Potential cladding material such as SiC-CMC must go through relatively low-cost, nonnuclear mechanical, thermal, and chemical characterization tests; only the best technologies selected by these tests will be used for in-reactor tests.\(^3\) This experiment investigates how Zircaloy-4 cladding tubes surrounded by a SiC-CMC sleeve behave under thermal stress. To simulate the heat generated by nuclear fission, electrical resistance heaters must be installed inside these cladding tubes. The assemblies will be tested in a hot water corrosion flow test loop – to simulate reactor water flow conditions – located at one of the INL facilities. The database would need to keep track of these throughout the sample preparation process: from the point of receipt at the laboratory through cutting, fabrication, test conduct and, ultimately, post-test analysis.

3.2 The Assembly Process

Test design specifications determined how as-received parts would need to be modified for the assembly of internally heated cladding rods (Figure 6). First, the Zr-4 is cut to an appropriate
size and the appropriate SiC-CMC sleeve is attached to the outside. The stock resistance heaters come with a metal sheath which must be removed. The ceramic coating over the resistor coils in the heater is then removed, and the heater is recast with a new ceramic layer of appropriate diameter. This heater is then coated with a lubricant and placed inside the cladding tube. This entire heater modification process is considered one process in the database.

![Diagram of internally-heated fuel cladding assembly process](image)

**Figure 6:** The internally-heated fuel cladding assembly process

Initial testing of these assemblies revealed an electrical issue. The internal thermocouples of the heaters were contacting the metal sheaths, which created significant error in temperature measurements. Even when isolated, the Zr-4 sheaths acted like antennae, altering the thermocouple voltage reading. The cladding assemblies had to be disassembled to address this issue. The Zr-4 and SiC-CMC cladding was saved, and the old heaters set aside. New heaters were recast with the same process, but with the thermocouple slightly adjusted. The total assemblies were fabricated again, using the same cladding tubes, but with the newly recast heaters.

### 3.3 Modifications to MIDAS

The sample preparation process for this experiment revealed the need for new features in MIDAS. Fabricated parts like the first internally heated cladding assembly might need to be taken apart, and their components recovered. In cases like this, using the cut control does not
make intuitive sense, as one single material is not being divided. The database required a function that could emulate the disassembly of a fabricated material, so the split function was developed. This takes the list of all materials that were combined into a fabricated part, and creates new records for these pieces, which are considered “recovered” (Figure 7). This function tracked the disassembly of the first internally heated cladding rods. Their recovered parts, with the heater replaced, could then be fabricated into new internally heated cladding tubes.

![SplitDialog](image)

**Figure 7: Disassembling a fabricated part**

Although the ID system provides a way to manually trace the history of a part, this can still be time consuming. The sample assembly process for the internally heated cladding tube experiment revealed the potential complexity of item histories. Tracing items back through processing or cutting is simple, but fabrication and disassembly are much more difficult to
follow. The part history function addresses this issue—it recovers an item's complete history and displays it as an Access report (Figure 8).

This function starts with the ID of the item to be investigated. If the part is cut or processed, it simply finds the record for the item's previous state by removing the suffix. If an item has been fabricated, it checks the source item field for the list of all its components, and follows their individual histories by calling itself for each of those components. The function will also include the fabricated item that a recovered part came from. In Figure 8, the source field lists the components of a fabricated assembly, and the fabricated item that yielded a given recovered item upon disassembly. Furthermore, the daughter field contains the list of parts that result from applying a function to a given part.

<table>
<thead>
<tr>
<th>Part History</th>
<th>Date</th>
<th>Type</th>
<th>Description</th>
<th>Comments</th>
<th>Source LWR5 ID</th>
<th>Daughter Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>LWR5-0072</td>
<td>5/20/13</td>
<td>Partly Consum</td>
<td>2/4 Tube; 12' length</td>
<td></td>
<td>LWR5-0072-C01; LWR5-0072-C02; LWR5-0072-C03;</td>
<td>LWR5-0074-P; LWR5-0074-P; LWR5-0074-P-F; LWR5-0074-P-R; LWR5-0074-R;</td>
</tr>
<tr>
<td>LWR5-0072-C01</td>
<td>5/20/13</td>
<td>Consumed</td>
<td>2' tube, SiC 11</td>
<td></td>
<td></td>
<td>LWR5-0074-P; LWR5-0074-P; LWR5-0074-P-F; LWR5-0074-P-R; LWR5-0074-R;</td>
</tr>
<tr>
<td>LWR5-0074</td>
<td>5/20/13</td>
<td>Consumed</td>
<td>SiC, 2ply 7 cycle</td>
<td></td>
<td>LWR5-0074-P-F; LWR5-0074-P-F; LWR5-0074-P-R; LWR5-0074-R;</td>
<td></td>
</tr>
<tr>
<td>LWR5-0074-F</td>
<td>5/20/13</td>
<td>Fabricated</td>
<td>SiC-clad internally heated 2ply SiC assembly SiC11</td>
<td></td>
<td>LWR5-0074-P-F; LWR5-0074-P-F; LWR5-0074-P-R; LWR5-0074-R;</td>
<td></td>
</tr>
<tr>
<td>LWR5-0076</td>
<td>6/24/13</td>
<td>Consumed</td>
<td>Waterline resistance heater</td>
<td></td>
<td>LWR5-0076-P; LWR5-0076-P-F; LWR5-0076-P-F; LWR5-0076-P-F;</td>
<td></td>
</tr>
<tr>
<td>LWR5-0076-P</td>
<td>7/1/13</td>
<td>Consumed</td>
<td>Modified heater</td>
<td></td>
<td>LWR5-0076-P; LWR5-0076-P-F; LWR5-0076-P-F; LWR5-0076-P-F;</td>
<td></td>
</tr>
<tr>
<td>LWR5-0072-C01-R</td>
<td>7/15/13</td>
<td>Consumed</td>
<td>2' tube, SiC 11</td>
<td></td>
<td>LWR5-0074-F; LWR5-0074-F; LWR5-0074-P-F; LWR5-0074-P-F;</td>
<td></td>
</tr>
<tr>
<td>LWR5-0074-R</td>
<td>7/15/13</td>
<td>Consumed</td>
<td>SiC, 2ply 7 cycle</td>
<td></td>
<td>LWR5-0074-F; LWR5-0074-F; LWR5-0074-P-F; LWR5-0074-P-F;</td>
<td></td>
</tr>
<tr>
<td>LWR5-0076-P-R</td>
<td>7/17/13</td>
<td>Fabricated</td>
<td>SiC-clad internally heated 2ply SiC assembly SiC11</td>
<td></td>
<td>LWR5-0072-C01-R; LWR5-0074-R-F; LWR5-0074-P-F; LWR5-0074-P-F;</td>
<td></td>
</tr>
</tbody>
</table>

Figure 8: The history of a fabricated part

4. CONCLUSION

By the end of the cladding tube assembly process, MIDAS proved to be a suitable tool for tracking materials used in scientific research. This experiment revealed essential features that needed to be added to the database software. The ability to cut, process, fabricate, or disassemble items should allow users to represent any changes made to materials. Most importantly, MIDAS
has the ability to identify any part's parents and children, as well as the complete history of the part. This ensures traceability of items used in research, makes it easy to verify the testing history of parts, and more. In the future, some additional functions could be made to further simplify database management. The need for such functions might become apparent as new experiments are conducted.

As the amount of data being tracked grows, the database might be converted to an SQL server. Compared to a simple Access file, server design has increased security and transaction logging – this is good for a project-wide file which multiple people may need to view and modify. For now, the streamlined material inventory organization will help LWRS more efficiently conduct research experiments, from simple characterization tests to in-reactor experiments. Since material states and the actions that can be applied to materials are universal in nature, MIDAS is suitable for tracking any kind of research – a generic version of the database is available for any research team to use.

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6. REFERENCES

