SIEL : HEAVY WATER INVENTORY SYSTEM

"Système d'Inventaire d'Eau Lourde"

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ABSTRACT

Heavy water is a very expensive resource and is also a prescribed material according to the Canadian Nuclear Safety Commission (CNSC). Since the commissioning of the CANDU-6 PHWR at Gentilly-2 in 1983, extensive efforts have been deployed to achieve effective and accurate heavy water management. Unfortunately, the tools available and the methods used in the beginning resulted in considerable uncertainties in the heavy water inventory after only a few months of operation. Since that time, improving heavy water management has always been a constant challenge and a goal. For these reasons, we developed an efficient, practical and modern new tool. SIEL is the result of the combination of all those experiences, successes, and failures acquired at G-2 over the years in D_2O management, and of the new technologies now available. The main purpose of SIEL is to **easily track the heavy water inventory and losses on a daily basis**.

1. INTRODUCTION

With the actual and constant high market price of heavy water (about 300$/kg), a power generating utility operating CANDU nuclear reactors cannot neglect the management of such a tremendous capitalization. This amount can easily exceed 150 million $CAN for only one CANDU-6 reactor. Furthermore, heavy water is a prescribed material according to the Canadian Nuclear Safety Commission (CNSC). Since the commissioning of the CANDU-6 PHWR at Gentilly-2 in 1983, extensive efforts have been deployed to achieve effective and accurate heavy water management. Unfortunately, the complexity of the systems, the tools available and the methods used in the beginning resulted in considerable uncertainties in the heavy water inventory after only a few months of operation. Since that time, improving heavy water management has been a constant challenge and goal for numerous technical managers and engineers. A few years ago, Those at Hydro-Québec decided to solve this problem once and for all! The objective was to develop an accurate, efficient, practical and modern new tool in heavy water management. So they created it: SIEL ("Système d'Inventaire d'Eau Lourde"). The primary goal of this new system was to easily track heavy water inventory and losses on a daily basis.

Of course, that was not an easy goal to achieve. Every CANDU nuclear reactor includes a highly complex network of heavy water systems, subsystems and reserves all interacting with each other and containing a total of at least 500 Mg of pure D_2O. The reactor itself, boilers, moderator system, clean-up and upgrading systems, numerous tanks, pumps and piping are examples of these systems. Fluctuations, processes, transfers between systems and various leaks occur every day during normal operation. Those variations, when added to instrumentation uncertainties, deficient system modeling and some unsuitable procedures, are the principal sources of improper heavy water management. So those were obstacles to be overcome by SIEL.

The aim of this paper is to introduce this new system. First, it presents the main objectives of SIEL, the description of all the system aspects and the main concepts used. Then, it describes the functioning of SIEL by giving an exhaustive review of what the system can actually do, how it does it and by showing actual screen figures. Finally, it discusses several other possibilities that may not be yet implemented into the system, but showing how precious and practical a tool SIEL can be for heavy water managers and users.

2. MAIN OBJECTIVES

To establish and maintain the heavy water (HW) inventory as accurate as possible

This is obviously the main target of SIEL. Gentilly-2 NGS manages grossly about 520 Mg of pure heavy water. Like it has already been said, that asset exceeds 150 million $Can. No wonder the owner wants to know how much he possesses and loses as accurately as possible at any time.

On a more technical point of view, managers, operators and others need to know how much D_2O is available, the way it is distributed among the systems, what is the HW quality (isotopic, tritium, impurities, ...) in these systems and also how much has been transferred from one system to another. Heat transport operating and economic reserves are other important data to monitor. All that information must be available at any time and updated as often as possible.

To periodically verify the D_2O situation by performing a physical inventory

To know the exact HW inventory and distribution at all times is nearly impossible. That degree of monitoring would require continued actions of operators and chemists whenever some condition changes somewhere in the plant. Also, some processes simply cannot be followed that closely because the state of these systems evolves slowly and continuously during normal operation. Dryers, clean-up and upgrading systems are good examples of systems performing such processes. Fortunately, in these cases, knowing the situation when the processes are completed is often good enough. The result is we cannot know 100% at all times.

Consequently, when it is impossible to know for sure, or we simply do not need to, the system must be able to calculate or extrapolate the isotopic content of a container. This happens mostly when some HW is transferred from one system to another. If after a period of operation, several of these calculated *transactions* have taken place, we can be sure that these contents will not be known exactly, as for the whole HW inventory. That is the reason why, regularly, the system performs what is called a *physical inventory*. In order to do that, the system calls for the level and the isotopic analysis of all the containers it needs in the plant. This allows SIEL to verify and correct its database according to the real HW situation in the plant. The HW manager determines the frequency of these physical inventories because, by using SIEL, he knows which data are calculated and which are physically verified. So he knows best when the time is right.

To evaluate D2O losses and releases (liquid and gaseous) to the environment

Mostly due to its possible radioactive content, heavy water releases to the environment are a primary concern for nuclear and public safety. Other concerns are economic ones. In SIEL, this is mainly a data acquisition task, because release measurements are taken independently by special monitoring systems. But SIEL presents those data in a useful way and compares them with what its inventory shows. This can be done easily, because the difference between successive inventories may be interpreted as HW losses. The losses calculated by the system are always different from what the measurements show. This difference may be partly caused by calculation uncertainties in SIEL, but it may also be caused by unmeasured losses from unexpected parts of the plant. Since the HW manager has to evaluate the real losses, SIEL, with its close monitoring of D_2O movements, can be a very powerful tool for tracking these unidentified losses.

To evaluate system leak rates, the recovery factor and some system performances

With its incredible data acquisition and analysis capabilities, SIEL allows the HW manager to closely monitor the system leaking rates. First, it determines how much HW was recovered by the dryer system. Then, the manager may decide to investigate further and try to find the most probable sources of the leaks. In addition, SIEL can do some statistics for you such as: how much HW was recovered by the collection systems, how much HW was upgraded or cleaned up during the past weeks and what was the recovery factor over the past year. A few examples showing how good a tool is SIEL for evaluating system performances.

To issue reports required by the CNSC, Operations, Accounting and Management

Of course, all that useful information SIEL can procure has to be presented in a formal, clean and professional way. With its considerable adaptability, the system can issue all kinds of reports, depending on the people concerned. The CNSC, Operations, Accounting, Management and others do not need the same information and certainly not at the same frequency. The different reports can be issued either monthly, quarterly or annually and can be printed out or sent as PDF files depending on the needs or preferences. SIEL has much useful information to give, but the people concerned must properly define their needs.

3. SYSTEM DESCRIPTION

SIEL consists of a software and hardware application combined with a set of new HW managing procedures. The software part is an impressive Visual Basic programmed application installed on the existing local area network (LAN) of the plant. Access to this application is possible by any authorized PC connected to the G2-LAN depending on the user's access level. It is the processor of SIEL being in constant communication with a huge database storing and retrieving information on all tanks, drums and fixed volumes containing D_2O. Everything that has modified the HW inventory is stored in the main database and is then available for consultation and analysis. Every new data or *transaction* affecting the HW inventory has to be validated against the existing information before approval and integration into the database. Part of the validation process is done automatically, but some has to be done by the HW manager, as every computerized system as to be validated. At the moment, the system uses a hidden Microsoft Excel worksheet to perform all its calculations. It was decided that way for the first release, due to the flexibility and the already defined scientific functions that Microsoft Excel offers. In addition, all G-2 equations of volume for containers were already on an Excel sheet. It is planned to have eventually all these equations hardcode and editable directly in the main application.

The SIEL hardware part consists of several portable data terminals (PDT) equipped with an optical barcode scanner and interconnected to the main application on the LAN. PDT's carry up-to-date information on all tanks and drums containing HW. By scanning the barcode of a container, all its parameters can be displayed: gross mass, D_2O, isotopic, tritium, conductivity, TOC, pH, oil and others. PDT's are also used for gathering data in the field: tank levels not wired to station computers, location of drums, D_2O transfers and chemical analysis results are examples of what can be done. The main groups involved with the use of the PDT are the HW Management team, Operations, Chemistry and Inspection.

SIEL is a new way of thinking in heavy water management. Its use requires a deep implantation in the operating procedures of the plant. **All HW manoeuvres must be entered into SIEL in order to succeed in adequate HW management, which is the primary goal of SIEL.** If such is not the case, SIEL will see and use the changes but the validation process would then be more complicated. So it is better that it becomes automatic to use and include SIEL in all the concerned operating procedures.

4. BASIC CONCEPTS USED

Before going further into SIEL tasks and capabilities, it is necessary to define and clarify its specific terminology to make sure the basic concepts used are well understood.

Smallest homogeneous containers (SHC): Smallest volumes, containing the same D_2O quality, that the system is able to compute separately. Currently, SIEL-G2 uses approximately ninety of them to calculate the whole inventory. This includes the calandria, tanks, fixed volumes, piping, filters, ions exchange columns and other special containers.

Request: This is the basis and the start of an information exchange in the system. It expresses the need for new data and action(s) to be taken. Requests can be generated automatically by SIEL or manually entered by users. All requests are associated with an object, a petitioner and an addressee.

Transactions: Entries that modify the system database when validated. Transactions are usually the addressee's responses to entered requests. Most of them have to be validated by the HW manager before being integrated into the database. Some of the more complex transactions are made up of several sub-transactions. Examples of these are the emptying of drums into a tank and the HW transfer between two tanks. Table 1 lists and describes the most commonly used associated requests and transactions.

Approval: At the present time, the transaction validation process is divided in two distinct steps. Approval is the first one. When a transaction enters the system, SIEL automatically qualifies it by giving a colour code status and brings it into the approval process. At G-2, the HW technician knows best what takes place in the field so his job is to give his approbation before the HW manager processes the transaction. At this point, he can see the details of the transaction, its given status and its effects on the concerned SHC. Also, he can change the transaction status and add his comments before approving it, which will send the transaction to processing.

Processing: It is the second part of the transaction validation process. At this point, unless it is *red coded* due to a problem, a transaction and its effects can be integrated or "processed" into the system database by the D_2O manager. Before doing so, the manager can analyse the effect of the transaction on the inventory and decide to edit or simply reject the transaction. He can also decide to send new requests to replace or complete the actual transaction. Once a transaction has been processed, it becomes part of the running inventory and its label and properties are logged in the database.

Delta-Mass: Difference in mass of D_2O generated by one or more transactions on the concerned container(s) or SHC. In theory, that difference should always be equal to zero, unless some HW has actually been lost. That mass difference comes mainly from calculation and measurement errors and deficient system modelling and tracking. It is probably the most powerful tool of SIEL, because it allows the manager to investigate deficient system modelling and bad field practices. The difference in mass of D_2O between two inventories is the sum of all transaction delta-masses during that period. And because all these delta-masses can be analysed individually, they become a powerful HW management tool.

Table 1: Most common associated requests and transactions in SIEL

Requests/Transactions (label)	**Possible addressees**	**Description**
To inventory drums (IN)	- HW technician - Field operators	- To inventory all drums in the specified room by simple barcode scanning
To shift a drum (SD)	- Field operators	- To shift a drum to the room specified
To weigh a drum (WD)	- Field operators	To weigh a HW filled drum and to enter the result on the PDT
To seize a level (SL)	- HW technician - Field operators	To manually seize the level of the specified container and enter the result on the PDT
To empty a container (EC)	- Field operators	- To empty a specified container into another one and to track the transfer with the PDT - Mostly composed of several sub-transactions such as SL and AN
To analyse a container (AN)	- Chemists	- To take a sample of the specified container and analyse the specified elements

5.0 FUNCTIONNING

5.1 Inventory browsing

Everyone having access to SIEL on the LAN can browse into the inventory for consultation. Inventory browsing is the most accessible and user-friendly part of the system. All the information concerning the updated HW inventory is displayed. Synopses of the heat transport system (HTS) and moderator system are presented. When browsing through these windows, users can click on any figure shown and get either to a more detailed synopsis of the chosen system or to a container detail window. When reaching the details windows, one can access every available information on that container, including mass of D_2O, level measurement, physical properties and chemical analysis. HTS synopsis and the detail window of a container are shown in figures 1 and 2.

There is other interesting information available for consultation, such as the drum list, which includes all drum locations and chemical analyses, HW measured losses and leaks and previously issued reports. All of those are presented in specially designed user-friendly screens. It is interesting to note that all essential information on containers and drums are also accessible on the PDT and can be consulted whenever users are in the field.

5.2 Parameter configuring and editing

Before doing any management job, SIEL has to be properly configured. Access to editing and configuring functions is very limited. Only one person should be able to change system parameters and it is not necessarily the HW manager. In fact, it is probably better that it is not because that person could do what he wants with the numbers. Hence there are two special access levels defined for that: HW Manager and System Manager. Of course, they may have to work together sometimes. The biggest part of the system configuration is the definition of all the *calculation parameters*. SIEL-G2 uses at the moment more than a thousand of them. These parameters can be seen as the architecture of the inventory calculation. They could be grouped in two categories: *INPUTS* needed by the system and *RESULTS* coming from the Excel Worksheet.

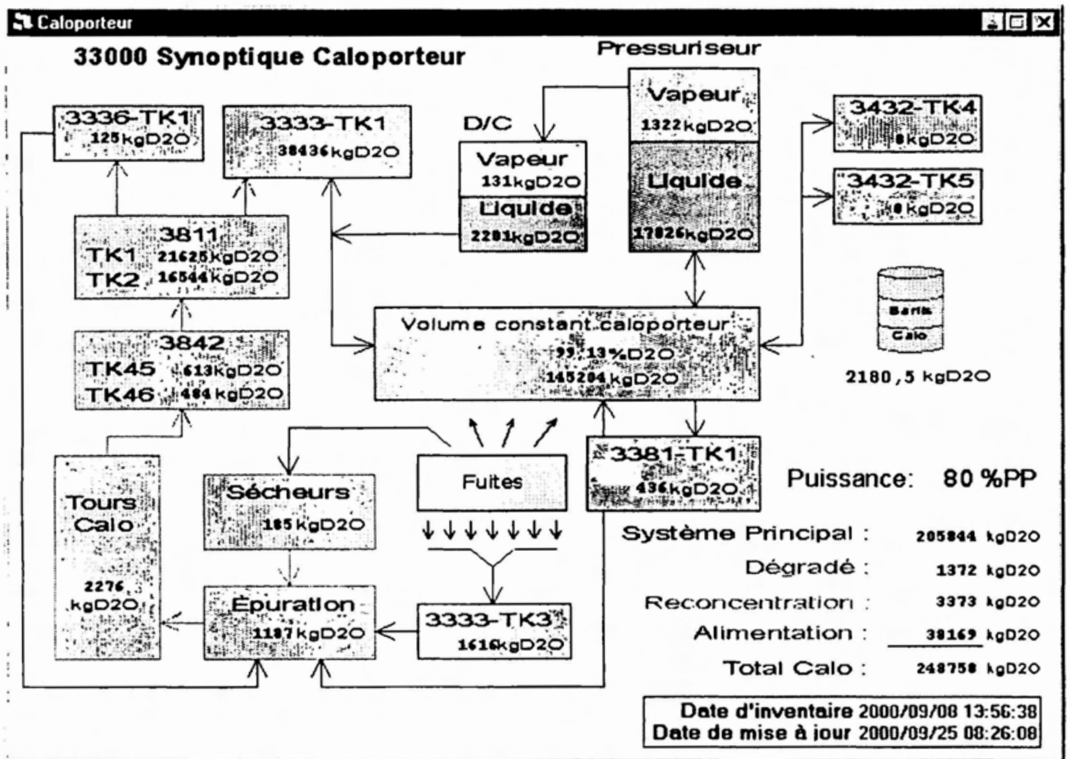

Figure 1: Heat Transport System synopsis screen

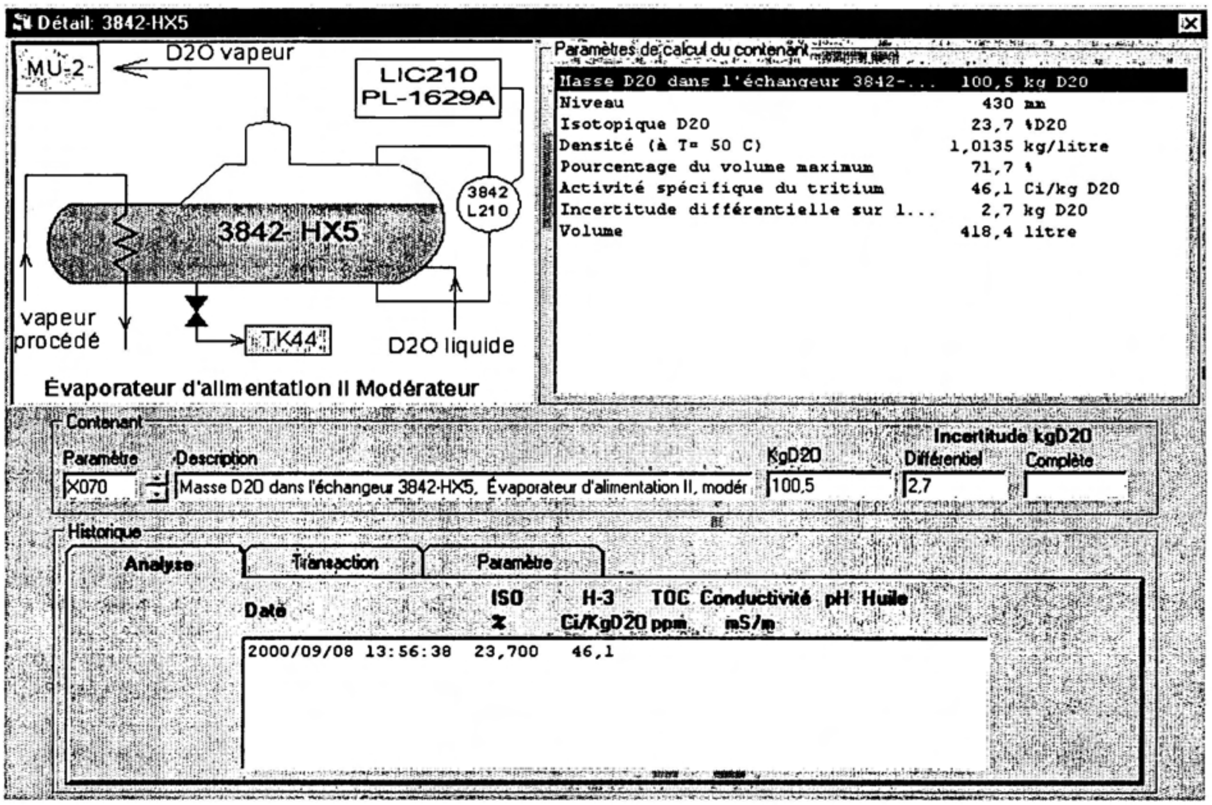

Figure 2: Detail window of the evaporator 3842-HX5

There are nearly 300 inputs needed by SIEL to perform the computation of the entire plant inventory. Fortunately, not all of them have to be updated each time you do so. And you can refresh the inventory quite often with SIEL. But the more inputs are updated, the more accurate becomes the inventory. Input parameters are distributed among all SHC of the plant and are mostly composed of container levels, D_2O isotopic, tritium contents and some physical properties such as temperature and pressure. There are several kinds of inputs. Many of them originate from the already existing data acquisition system of the main control computers of the plant (STDE). The HW manager generates the requests for these instrumented inputs when he needs them and the parameters arrive automatically into the system. Another important type of input consists of those that have to be manually integrated in the system with the use of the PDT. These inputs are mainly composed of un-instrumented tank levels, chemical analysis results and drum locations. The HW manager also generates the requests for these manual inputs. But in order to receive the request and send the data, the concerned users have to perform a communication between their PDT and the main application. All the other inputs are generated automatically by SIEL. They are either deduced or calculated from other inputs.

The other category of calculation parameters to be configured is the results one. As mentioned before, these parameters are results coming from the Microsoft Excel worksheet. Whenever some new input enters the system, SIEL sends this information to the worksheet, which recalculates the concerned parameter(s) and retrieves the new results. These results parameters are mostly composed of D_2O masses, volumes, densities and mass uncertainties.

In addition to the calculation parameter definition, the editing or configuring tasks of the system manager include drums, containers, chemical parameters and some other technical and utilities configuration.

5.3 Heavy water managing

HW managing is of course a primary task of SIEL. It is designed to be the most helpful tool of the HW managing team. In order to do that, the system must be able to track all HW movements as closely as possible. The more data the system will gather and treat, the more accurately the D_2O situation in the plant will be known. The amount of information gathered and the rate at which the system does it depend mostly on the HW management needs. Also, it could be stated that it depends on the HW management ability to validate and process all the data SIEL is able to supply. Let us now see what tracking HW with SIEL is all about.

HW system configuration

First of all, the configuration of the HW systems may vary in time. Following are some questions that the HW manager has got to answer while following the HW evolution: Which tank content is being or has been processed in the clean-up system? Which tank has been feeding the upgrading system lately? Have the dryers' performance parameters changed recently? The answers to these questions and others are necessary in order to associate properly the deduced calculation parameters mentioned earlier. Despite what it may seem, that HW manager task is fairly easy and should not take more than ten minutes a day.

Information gathering and transmission

On a daily basis, the HW management team either needs new data or has instructions to give to field operators. All the inputs that can be provided by the data acquisition system from the main control computers may be *requested* every day automatically. To do so, the HW manager only has to define an appropriate request profile by choosing the inputs needed, at what time and at which frequency, if not daily. That procedure enables the manager to be notified when any situation has evolve significantly, because these requested instrumented *inputs* are sent automatically into the SIEL validation process as new *transactions*.

When the required data is not available on the acquisition system, the process of information gathering is quite different. First, the HW manager or technician has to enter a specific request in the main application. That request could be to manually seize one container level and would be addressed to field operators or it could be to sample and analyse the content of a SHC and would be addressed to Chemistry. Once the request is entered in the system, it is transferred to the addressee as soon as he communicates with the main system with his PDT. At that point, the addressee is ready to answer the request by getting the information needed in the field and entering it on his PDT. When that is done, the addressee re-communicates with the main system with his PDT. During that communication process, the information needed is sent to the validation process as a new *transaction*.

In addition to data inquiry, it is also possible to address field instructions with SIEL. Such instructions might be to empty a container into another, to empty drums into a tank or simply to move drums from one room to another. The procedure used to do that is similar to the one explained above. The requests are entered and transferred to the PDT. The addressee executes the instructions with the PDT, while entering new data on it. Then the information is sent back to the main system as new transactions to be validated. The case of container emptying is a good example of a composed transaction. When it arrives in the system, it is formed of several sub-transactions such as container levels and analyses. As can be seen, the number of requests and information that SIEL can treat is also limited by the amount of work that operators, chemists and others can do in the field.

Data processing and validation

New data arrive in the system as *transactions*. Before the HW inventory can be updated with this new information, the upcoming data have to be validated by the HW management team. The transaction validation process was introduced earlier in the *basic concepts used* section of this work. In G-2, it was decided to divide the validation process in two steps: approval and processing. Since two different persons do these steps, it can be seen as a double verification process. In addition, the HW manager and technician may not have the same interest towards some type of transaction. The HW technician may be more interested to track the field processes such as drum management and clean-up system whereas the HW manager may pay more attention to track significant HW transfers between systems. In either case, they both have to validate each new transaction.

Transactions arriving either automatically or from a PDT communication, are sent directly to the approval process with a qualification status (colour code). This process is done on a screen very similar to the one shown on figure 3, which presents a processing screen. At this point, every transaction can be approved, no matter what the status code. A simple click allows the selection of one transaction to be approved. Pushing the command button gives approval of all selected transactions. If the transactions have to be investigated further, a double-click on the desired transaction gives access to the bottom part of the screen where two tabs are available. The first tab, named validation, describes the data, gives the reason of the status code and offers some solutions to the users. Actions here are limited to changing the status code to a more "caring" one, adding comments and creating a non-existing SCH (drum) while entering new requests concerning it such as to weigh and analyse it. The second tab presents the mass calculation of the concerned SHC before and after the transaction is applied. Once approved, transactions are sent to processing, the second step of validation.

Processing is very similar to approval, except that errors and inconsistencies in transactions can be corrected here. In fact, sometimes they have to be corrected because red coded transactions simply cannot be processed. Double-clicking on a transaction brings it in the validation and mass calculation tabs, where the HW manager can analyse, edit or simply reject the transaction. There is a special case for the emptying type transactions, since they are composed of several sub-transactions. Once brought in the validation tab, a simple click on the transaction label or on the mass calculation tab brings the user to a special processing screen, showing all the sub-transactions of the emptying. In that screen, every sub-transaction can be analysed and treated separately. Also, the screen offers the possibility of addressing new requests concerning the SHC involved if necessary.

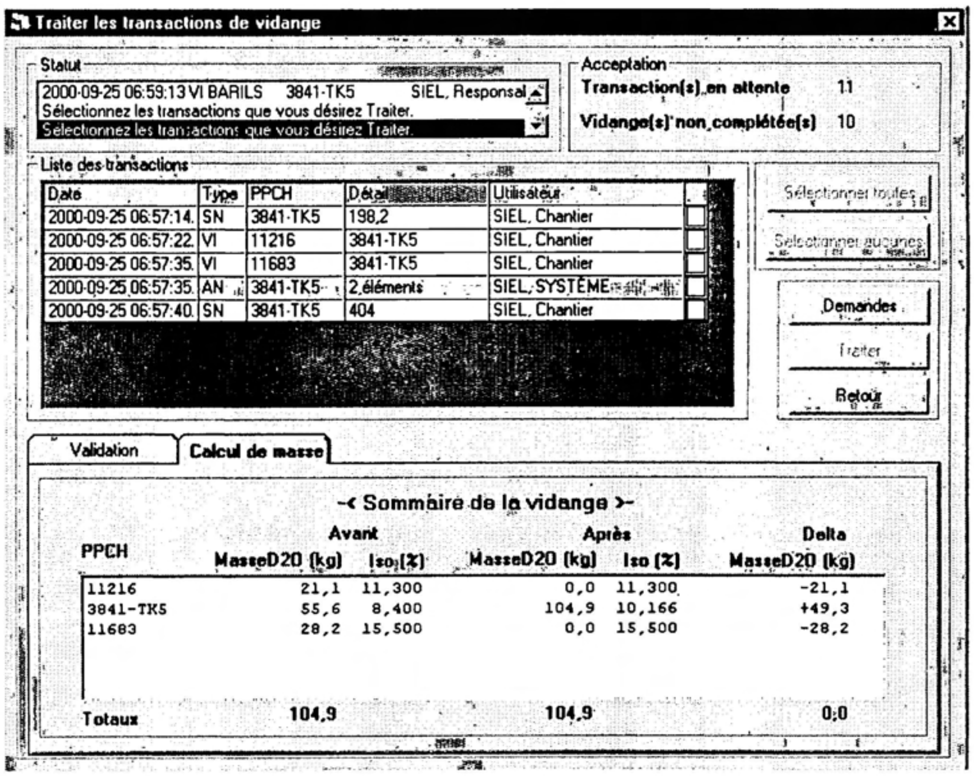

Figure 3: Special processing screen of the transaction of emptying drums # 11216 and # 1683 into the clean-up system tank 3841-TK5

That special processing screen is presented in figure 3. It shows the emptying of two drums, labelled # 11216 and # 11683, into the clean-up tank 3841-TK5. All sub-transactions are presented: the tank level before the transaction, the two transfers and the level and analysis of the tank after the transaction. In that case, the isotopic was calculated by the system. But the HW manager could ask for a real analysis by entering that request with the command button ("Demandes" in French). The mass calculation tab is opened for the whole emptying transaction. Every sub-transaction could be analysed separately in that screen. It is interesting to note that the delta-mass is zero. This is due to the isotopic calculation of the tank by the system which supposes a perfect transfer. Emptying transactions must be selected and processed as a whole. When back in the processing main screen, every selected transaction (one click) will be processed to the inventory updating by pushing the right command button.

Physical and updated inventory

Before the inventory database is updated with the processed transactions, the new data is sent to one last screen, the inventory one. This is to allow the HW manager to visualize the effects of the processed transactions on the whole plant inventory. It is built with hierarchical views, where all system levels can be displayed with their affecting processed transactions. That screen enables the user to see the HW contained before and after the transaction was processed. The variations or delta-masses appear either in the containers involved or in the whole system, depending on the visualizing level. By adding all the variations, SIEL shows the effect of the transactions on the whole plant inventory. All the affected inputs can also be consulted in a special tab. That screen also offers the possibility to compare the new data with the ones of the last official inventory, in order to see the HW evolution during that period. Many processed transactions can accumulate there before the manager decides to update the inventory.

That screen is shown in figure 4 for the emptying transaction discussed in figure 3. The Heat Transport system is opened to the most detailed view level and the transaction affecting 3841-TK5 and drums is shown. The delta-masses for tank 3841-TK5 and Heat Transport drums sum to zero. So that transaction had no effect on the total inventory.

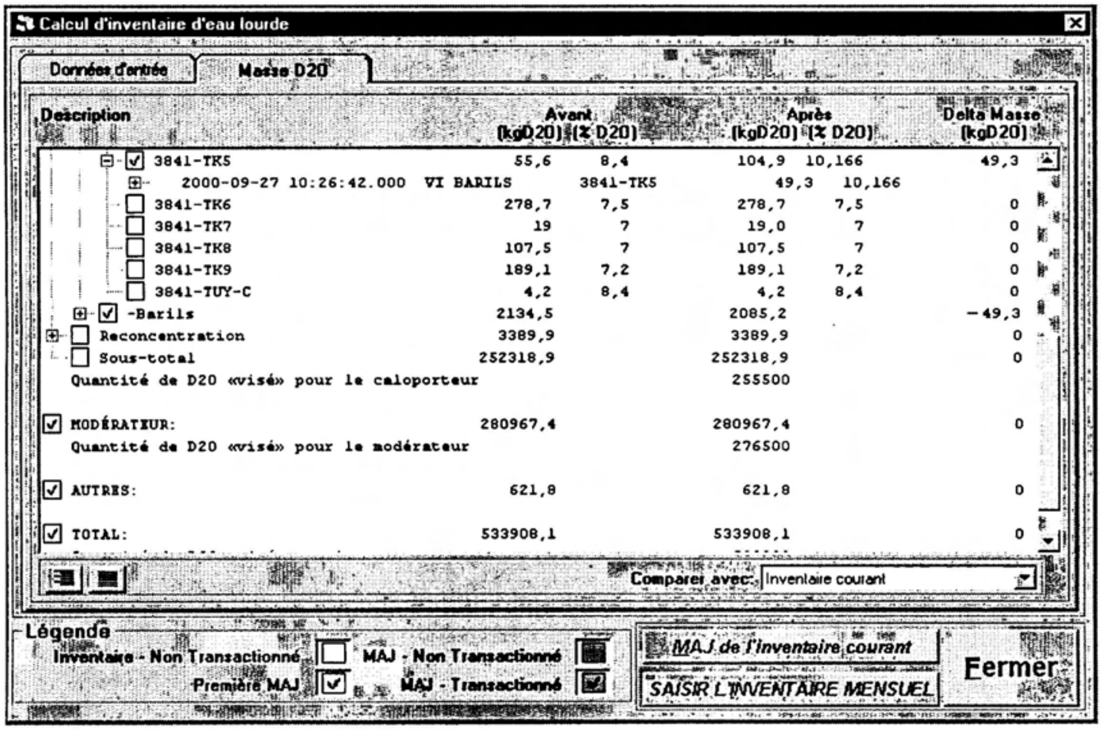

Figure 4: Inventory screen of processed transactions

When the HW manager believes it is OK, he only has to push the updating command button and all the inventory will be updated with all the processed transactions. That does not mean that there is a new official inventory. There is also a command button for that. But this updated inventory is assumed to be good and will be presented in all the consultation screens. In G-2, official inventories go along with the physical inventories. For those, an impressive number of special requests is entered in order to receive all the levels, isotopic analyses and other data the manager needs to perform such an inventory. Usually, this is done once a month. HW reports are issued from these physical inventories.

5.4 Future possibilities

In addition to daily HW tracking, the SIEL' designers and HW managers at Hydro-Québec can think of a whole lot of other interesting possibilities. Refining system modelling is the first one to be thought of since it is so easy and fast to perform any container calculation. It could even include a re-commissioning procedure for container equations with curve fitting functions. It could become the operating reference for complex systems such as the HW upgrading system. That list could be continued for long because with a tool such as SIEL, possibilities are endless...

6. CONCLUSION

Because of technical, safety and economic reasons, heavy water is an important resource to manage for utilities operating CANDU nuclear reactors. Since SIEL' main objectives are to track the HW inventory as accurately as possible, to evaluate the losses and to issue the required reports, it is a perfect tool for that. The designers of SIEL, including the author of this paper, think they have succeeded and are very proud of the product they have created. It is powerful, very effective and easy to use and no equivalent can be found in the industry. SIEL was once a vision, now it is a reality **deemed to be the ultimate tool in heavy water management**.

In case you are interested, please note that SIEL could be adapted for any CANDU nuclear plant and that it will be ready to be officially released on the market for sale very soon. For any question or more information, the author can be contacted at any time.

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