A STUDY OF AN INTELLIGENT FME SYSTEM FOR SFCR TOOLS

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ABSTRACT
In the nuclear field, the accurate identification, tracking and history documentation of every nuclear tool, equipment or component is a key to safety, operational and maintenance excellence, and security of the nuclear reactor.

This paper offers a study of the possible development of the present Foreign Material Exclusion (FME) system using an Intelligent Nuclear Tools Identification System, (INTIS), that was created and customized for the Single Fuel Channel Replacement (SFCR) Tools. The conceptual design of the INTIS was presented comparing the current and the proposed systems in terms of the time, the cost and the radiation doses received by the employees during the SFCR maintenance jobs. A model was created to help better understand and analyze the effects of deployment of the INTIS on the time, performance, accuracy, received dose and finally the total cost. The model may be also extended to solve other nuclear applications problems.

The INTIS is based on Radio Frequency Identification (RFID) Smart Tags which are networked with readers and service computers. The System software was designed to communicate with the network to provide the coordinate information for any component at any time. It also allows digital signatures for use and/or approval to use the components and automatically updates their Data Base Management Systems (DBMS) history in terms of the person performing the job, the time period and date of use. This feature together with the information of part's life span could be used in the planning process for the predictive and preventive maintenance.

As a case study, the model was applied to a pilot project for SFCR Tools FME. The INTIS automatically records all the tools to be used inside the vault and make real time tracking of any misplaced tool. It also automatically performs a continuous check of all tools, sending an alarm if any of the tools was left inside the vault after the job is done.

Finally, a discussion of the results of the system feasibility was performed and further INTIS applications were suggested.

KEYWORDS
Single Fuel Channel Replacement, SFCR Tools, RFID, Smart Tags, Tools, Foreign Material Exclusion.

1 INTRODUCTION

As a rapid developing technology, the RFID smart tags attracted the attention to the potential uses of such a leading-edge technology to identify the nuclear components. Having a category of the RFID tags specially designed for high radiation hazardous environments, the idea of using the RFID smart tags became more worthy to investigate. These tags withstand a radiation of 45 k Gray (4.5 G. RADs) with no effects on their functions.

RFID tags are divided into 2 categories, passive and active. The passive tags consist of a small electronic chip surrounded with an on-board antenna for communicating with the readers. As the reader sends the energizing signal, a low current (but sufficient to read the chip data) is generated and fed to the tag chip. The chip communicates with the reader sending all the data stored in its memory (up to 2 Kbytes). A unique code is usually recorded at the tag's memory to identify the tagged component. The active tags do not need energizing signals, since they have small batteries as a source of energy.

The tagged component could be sensed with the tag reader from a distance varying from several centimeters to several meters thorough non metallic barriers. Moreover, the tagged item can be tracked to find its location within the monitored work areas.

In most of the cases in the nuclear field, the identification of the items relies on experienced peoples reading the paper tags prepared to indicate the state of nuclear components. This human based manual identification system currently used in nuclear field results in extra radiation doses and less time effectiveness as well as possible human errors. The application of the suitable RFID technology to identify the different nuclear components may lead to the following advantages:

1. Reduced radiation doses received by workers.
2. Reduced total time to complete the job.
3. Reduced probability of errors due to less human interaction.
4. Reduced cost per job and hence reduced overall total cost.
5. Improved quality of the Information Flow System in terms of better communications and history recording, as linked to the components data base.
6. Improved "Learned Lessons" recording, search and usage.
7. Improved analysis of work times and hence better planning for future work.
8. Better planning of tools maintenance based on the fixed updated data recorded to the active DBMS.
9. Automated confirmation that the right person uses the right tool.
10. Automated verification that the worker's training qualification is still valid and it is legal to operate the nuclear system.
11. Automated confirmation that the tool's calibration is valid.

2 THE SYSTEM CONCEPTUAL DESIGN

The concept of the INTIS is to identify the unique codes of the different tools and peoples, recognize their places at different times and get this information recorded electronically into transaction files, or T-Files. These T-Files are utilized by an Artificially Intelligent (AI) module to decide when, where the tools were used, lost or misplaced, and who is the person involved. They are also used to determine the tools left in each work area, and hence the AI module can send an alarm to remind the operator that some forgotten tools in places where they should not be left (for example, the reactor vault). This way INTIS makes sure that the tools are not left behind at the vault as components of FME.

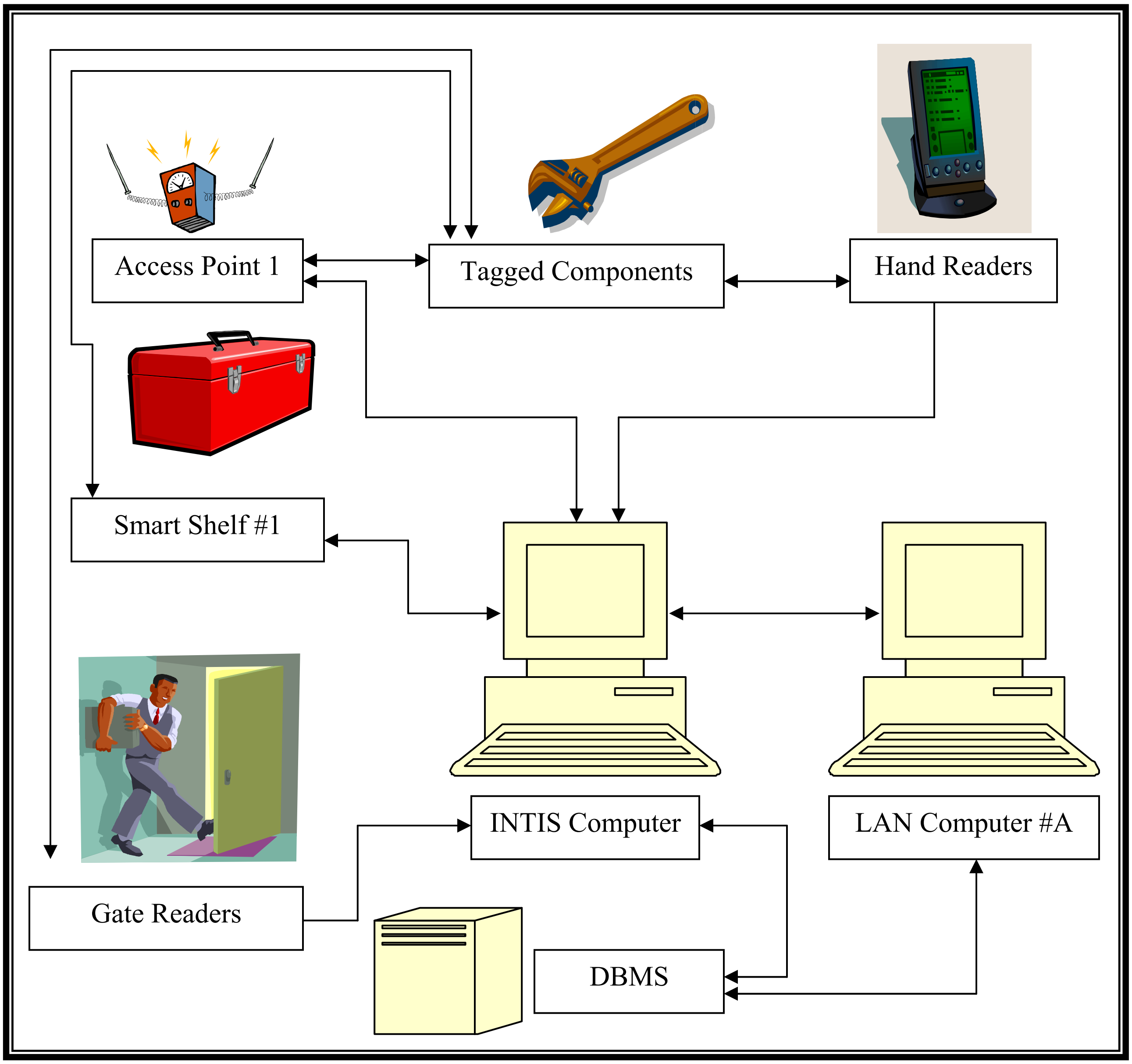

Figure (1), Schematic INTIS components connections.

The basic INTIS components are:

- RFID computer(s).
- Communication devices to Dbase computer and other LAN computers.
- Suitable tags to be placed on different tool's components.
- Access points for tracking of the tagged components.
- Hand reading and processing units.
- Gate readers.
- Smart shelf components.
- System integration software.
- Artificially Intelligent (AI) Module.

Figure (1) shows the different components of the INTIS as well as the communications among them.

2.1 INTIS Computer:

The INTIS computer is the hardware that handles the RFID signals received from the different readers, smart shelves and access points via suitable interfaces, runs the AI and Integration modules to perform the required mathematical and logical operations, time measurements and decisions needed on the real time. It also performs the required searches, dbase updates and communicates the proper messages to the user via the available output devices.

2.2 Communication Devices:

The Communication between the RFID computer, the Dbase computer and other LAN computers is established by communication devices as a part of LAN management system.

2.3 RFID Smart Tags:

Different types of tag with different specifications and sizes are available in the market. Suitable tags are selected and placed on the nuclear component or tool based on its function, size, contact areas and the way it is handled. The RFID tags are initiated with write operation of a unique identification (ID code) that represents each part, tool or component. Different digits of the ID code tell the computer the category and the group ID codes as well as the tool code.

2.4 Access Points:

Access points are special coordinates readers located in different work areas for tracking of the tagged components. Three units per work area are recommended to accurately locate the tools coordinates.

2.5 Hand Readers:

The Hand Readers are reading and processing units used to read or write the tool RFID tag in case of power loss or any emergency that impacts the INTIS hardware. The Hand Readers are battery operated and can provide detailed information about the tools with out connection to the RFID computer. The Hand Reader is also used for tracking and finding the lost or misplaced tools.

2.6 Gate Readers:

Gate readers are fixed in wall or ceiling and used to monitor the tool passing from a certain gate. More than one reader may be needed at the same gate based on the reader's accuracy, the gate dimensions and the required reliability level.

2.7 Smart Shelves:

A Smart Shelf is a plain surface with embedded readers that identify the tools placed on the surface. As it communicates with the RFID operating software, if the tool inventory is changed, the software will recognize the missed or added tools. Each smart shelf may contain one or more embedded readers. If it uses more than one reader, the places of the tools, within the shelf area, could also be communicated to the processing software module.

2.8 Artificially Intelligent (AI) Module:

The AI module uses the transaction files (T-Files) as well as other information and data files to decide when and where the tools were used, lost or misplaced, as well as who the involved person is. The AI module determines the tools inventory within each work area, and hence an alarm for the forgotten tools may be sent to alert the users that some tools are in places where they should not be (for example, the reactor vault). The AI module also checks the calibration data for each tool, and alarms the user if any tool needs to be recalibrated. For tools that need special training, the AI module checks that a properly trained person, whose qualifications are still valid, uses the tool.

2.9 System Integration Module:

System integration module is the software module that logically connects all the previous items together to work in harmony and communicates the received signals to the RFID processing module, AI module, and Dbase information systems (for all the tools, workers and Transactions) in the proper format for data processing and decision making.

3 THE INTIS MODEL DEVELOPMENT

The INTIS has both logical and mathematical models. The logical model was developed to ensure the INTIS integration. That is the system's hardware and software components are integrated and are working in harmony with each other. The mathematical model was developed to measure the benefits of INTIS application in terms of time, dose and cost reductions.

3.1 The INTIS Logical Model:

The System Integration is the process of getting all the INTIS components to work together with the different software systems in harmony. This is mainly achieved by developing a logical model, identifying the inputs and the outputs of each component as well as the flow of information among the different components.

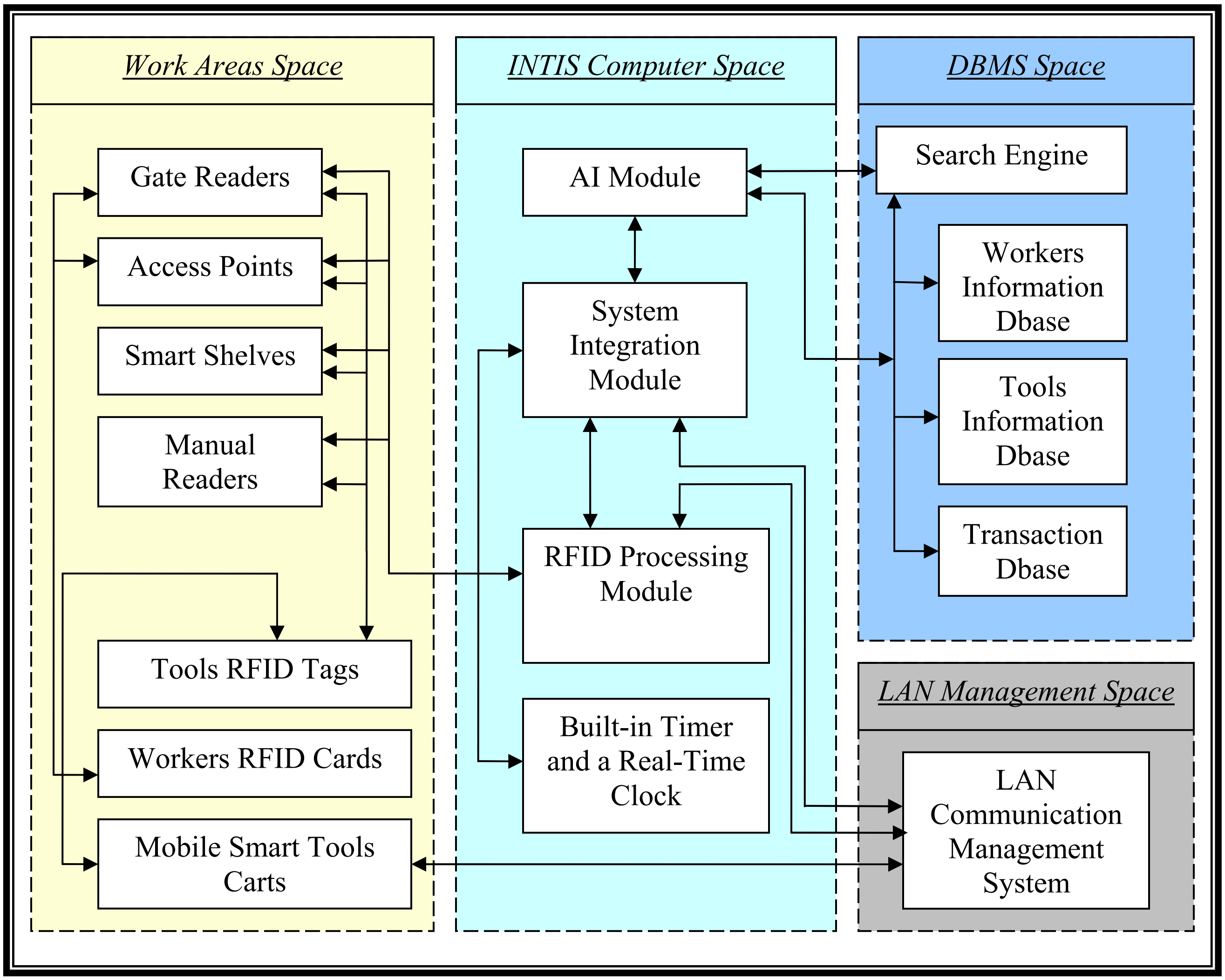

Figure (2), The INTIS logical model

The logical model consists of 4 spaces that communicate information among their components to get different operations accomplished. These spaces are:

- Work Areas Space,
- INTIS Computer Space,
- DBMS Space, and
- LAN Management Space.

Figure (2) shows the INTIS logical model, indicating the information flow among different spaces and their components.

As the system user selects an operation, the System Integration Module communicates with the RFID Processing Module to send an activation signal to read the Smart Tags within the requested work areas. The ID Code is read by the different readers in the requested work areas and sent to the RFID Processing Module either directly of via the LAN communication Management System. The RFID Processing Module communicates the ID codes to the System Integration Module, which, in turn, communicates the ID codes with the real time value to the AI Module to logically process the information and get the required reports ready for use. The System Integration Module, depending on the operation selected, may communicate the tool data, worker data and T-Files to the AI Module, should it be needed for smart data processing.

If no operation is selected, the system repeatedly starts a read operation every 3 seconds. All the tags at each the work area are recognized and recorded to a T-File together with the time of reading. The T-files are then used to update the work areas inventory data bases.

To identify each tagged tool or part used on the reactor face at the real time, the INTIS issues a read operation for all the tag IDs within the relevant work area, search for each tag ID in the proper data base and pass all the information with the reading time to the AI Module for processing and get the ready to use reports.

The system also allows digital signatures for use and/or approval to use the Tools. If the tool is set to the option digital signature required, the system will continuously monitor the tool and an alarm is set on if the person moves the tool without scanning his ID tag card. It automatically updates their DBMS history in terms of the person performing the job, the time period and date of use.

If the end of the shift operation is selected, the system will perform a read operation for all work areas including the reactor face work area. The system then matches the information with the last inventory information, detecting the tools transfer that took place. Based on the read and recorded data, an alarm is set on if any tool entered to the vault and did not exit.

If a tool happens to be lost or misplaced in an area that is not within the reading range, the system will get the last information when the tool was detected. The work area where the tool was detected, let us say Area #3, the system will try to locate the Tool at both areas #2 and #4. If not found, manual tracking of the tool will be performed.

3.2 The INTIS Mathematical Model:

The mathematical model for the INTIS was based on the task analysis of SFCR procedures. On implementing the INTIS, and if the daily work involves a set of tasks with different repetitions of each task, the total time saving in N days of work, at a confidence level of (1-α), may be calculated as follows:

$$\Delta T = N.\sum_{i=1}^{M} k_i.\{(\mu_i - \mu_i^{'}) \pm z(\sigma_i + \sigma_i^{'})\} \quad \ldots\ldots\ldots\ldots \quad (1)$$

As:

$$\Pr\{-z \le Z(T^{'}) \le z\} = (1-\alpha) \quad \ldots\ldots\ldots\ldots \quad (2)$$

$$\Pr\{-z \le Z(T) \le z\} = (1-\alpha) \quad \ldots\ldots\ldots\ldots \quad (3)$$

$$Z(T^{'}) = \frac{T^{'} - \mu_i^{'}}{\sigma_i^{'} / \sqrt{n^{'}}} \quad \ldots\ldots\ldots\ldots \quad (4)$$

And:

$$Z(T) = \frac{T - \mu_i}{\sigma_i / \sqrt{n}} \quad \ldots\ldots\ldots\ldots \quad (5)$$

Where:

k_i	is an integer representing the repetitions of the i[th] task per day.
σ_i	is the standard deviation of the i[th] task without INTIS implementation.
μ_i	is the mean time to achieve the i[th] task without INTIS implementation.
$\sigma_i^{'}$	is the standard deviation of the i[th] task after INTIS implementation.
$\mu_i^{'}$	is the mean time to achieve the i[th] task after INTIS implementation.
ΔT	is the total time saving at N days due to implementation of INTIS.
M	is the number of the daily tasks of interest.
z	is a real number which depends on the required the level of confidence.
Pr	is the probability that $Z(T)$ occurs within the limits $\pm z$.
T	is the experimentally measured time value in seconds without INTI.
T'	is the experimentally measured time value in seconds with INTI.
n	is the sample size tested before INTIS implementation.
n'	is the sample size selected after INTIS implementation.

As the normal distribution is considered at a specific confidence level, the real number z could be then calculated as follows:

$$\Phi(z) = \Pr\{Z(T) \leq z\} = [1 - \frac{\alpha}{2}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

$$z = \Phi^{-1}[1 - \frac{\alpha}{2}] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

The total saving in cost of the job depends on the task packages performed on the critical path or on any other non-critical path that have float. If the tasks are on the critical path, the project time will be decreased leading to a significant saving in cost due to decreased period of the reactor shut down. Cost saving in tasks on a non-critical path will impact labor and tool costs but not the cost of reactor shut down. This may be mathematically represented as follows:

$$\Delta C = N.\sum_{i=1}^{M} k_i.\{(\mu_i - \mu_i') \pm z(\sigma_i + \sigma_i')\}.(Ct_i + Cl_i + Cr_i.k_p) \quad \ldots\ldots\ldots\ldots \quad (8)$$

Where:

ΔC is the total cost saving at N days due to implementation of INTIS.
K_p is an integer equals 1 if the task is on the critical path and equals 0 elsewhere.
Ct_i is the sum of tools costing per unit time.
Cl_i is the sum of labor costs per unit time. This includes the labor training cost.
Cr_i is the total cost for the reactor shut down per unit time.

The dose saving (ΔD) could be also formulated as follows:

$$\Delta D = N.\sum_{i=1}^{M} k_i.\{(\mu_i - \mu_i') \pm z(\sigma_i + \sigma_i')\}.(Dt_i.k_d.NL) \quad \ldots\ldots\ldots\ldots\ldots \quad (9)$$

Where:

K_d is a constant represents the radiation intensity correction factor.
Dt_i is the average dose per unit time received by the labor to achieve the i^{th} task.
NL is the number of laborers performing the i^{th} task.

4 THE INTIS APPLICATION (A PILOT PROJECT)

As a pilot project, the INTIS was applied to SFCR tools. Approximately 6% of the SFCR tools were tagged with RFID Smart Tags and a full software/hardware INTIS was implemented in place. Certain work tasks were elected to undergo a time study to help numerically evaluate the performance of the INTIS. The mathematical model shown in point (3.2) was then applied and the results were discussed.

4.1 The INTIS Pilot Project Evaluation

In order to evaluate the possible performance improvement of the suggested INTIS, the following selective tasks were subject to time study with and without the INTIS utilized. Historical and subject matter expert information was used when possible.

Task1: Correctly find and identify the required tools from the storage area, place them on the cart then move it to the reactor floor, completing the Foreign Material Exclusion Area Accountability Log, N-Form-10981-R002.

Task2: Select the required tools from the rubber area, place them on the cart then move to the bridge work area filling the FMEA Accountability Log.

Task3: Check the tools inside the Tool Box and validate the tool Box Log.

Task4: Create the Foreign Material Exclusion Area Drop Log, N-Form-110038-R00.

Task5: Finding the lost tools inside and outside the vault.

Task6: Making tools inventory to check that every tool is in place and the calibration of all the tools is up-to-date.

Task7: Updating the tools data base with the time of use of each tool, lost or broken tools and task achievement report (failure / success).

The measurements of the time taken to perform each task were recorded for 5 workers repeating the same task, and then the mean values were calculated. The measurements were repeated for all tasks with and without the help of the INTIS. Table (1) shows the results of the time study before implementing the INTIS, while Table (2) shows the time study of the same tasks utilizing the INTIS.

Table (1), Time study of the different tasks without implementing the INTIS:

	Read1 [min]	Read2 [min]	Read3 [min]	Read4 [min]	Read5 [min]	Mean μ_i [min]	Standard Deviation [σ_i]
Task1	20	21	22	21	20	20.8	0.83666
Task2	35	34	33	35	35	34.4	0.8944272
Task3	36	32	33	35	34	34	1.5811388
Task4	10	10	11	12	10	10.6	0.8944272
Task5	1440	1440	1440	1440	1440	1440	0
Task6	50	55	54	53	55	53.4	2.0736441
Task7	15	15	16	14	16	15.2	0.83666

Table 2, Time study of the different tasks after implementing the INTIS:

	Read1 [min]	Read2 [min]	Read3 [min]	Read4 [min]	Read5 [min]	Mean μ_i' [min]	Standard Deviation [σ_i']
Task1	7	6	7	8	7	7	0.7071068
Task2	14	15	14	13	15	14.2	0.83666
Task3	0.5	0.5	0.5	0.4	0.3	0.44	0.0894427
Task4	0.4	0.4	0.5	0.3	0.4	0.4	0.0707107
Task5	5	6	6	5	5	5.4	0.5477226
Task6	0.8	0.7	0.9	0.6	0.7	0.74	0.1140175
Task7	1.4	1	1.2	1	1	1.12	0.1788854

4.2 Discussion of the Results

Applying the mathematical model to calculate the time saving ΔT**,** the dose saving ΔD and the savings in the cost ΔC was performed. Darlington reactor's input values for time, costing, and doses were used. An outage window of 15 days was assumed and the calculations were made at a confidence level of 98.8%. (***z* = 2.5**). Only 30% of the tasks were assumed to be on the critical path. A total dose of 35 REMs/person and a 0.7 radiation intensity correction factor were assumed.

The resulting savings in time, dose and cost were: 158 ± 6 Hrs, 16 ± 0.6 REMs/person and $2,396,964 ± $91421 respectively. The percentage savings for the three parameters were: 65.97%, 46.18% and 20% respectively.

Figure (3) shows a graphic representation of the percentage savings in time, dose and cost during this outage window.

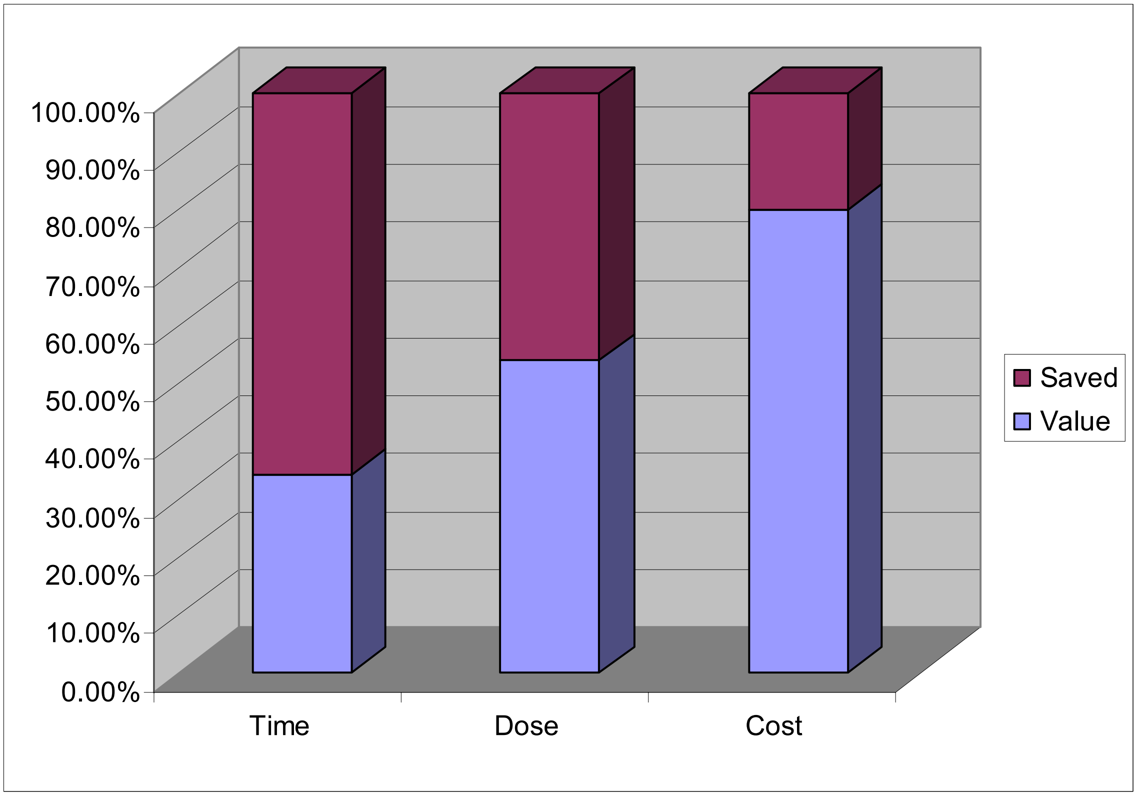

Figure (3), The Percentage Savings on Application of INTIS

5 CONCLUSION

The Foreign Material Exclusion (FME) system was enhanced using an Intelligent Nuclear Tools Identification System (INTIS) created and customized for the Single Fuel Channel Replacement (SFCR) Tools. This INTIS is based on the use of Smart RFID Tags for tools' identification. The design, modeling and testing of the INTIS was created to suit this application. As a case study, the INTIS was applied in a pilot project to numerically evaluate the advantages and disadvantages of INTIS implementation.

Comparing the current system to the INTIS, in terms of time, cost and radiation received by the employees during the SFCR maintenance jobs, showed INTIS superiority. In addition to the automated data processing and the friendly GUI, the INTIS savings in time, dose and cost were 65.97%, 46.18% and 20% respectively at 98.8% confidence level.

The system also allows digital signatures for use and/or approval to use the components and automatically updates their DBMS history in terms of the person performing the job, the time period and date of use. This feature together with the information of part's life span could be used in the planning process for the predictive and preventive maintenance.

The system is suggested to be rolled out to other nuclear areas that could benefit of its merits.

6 REFERENCES

1. Hassan, Hassan A., "TOWARDS A DEFINITION OF ARTIFICIAL INTELLIGENCE", 1st International Conference of AI, Cairo, Egypt, 1993.
2. Tsai, H. et al, "APPLYING RFID TECHNOLOGY IN NUCLEAR MATERIALS MANAGEMENT", Proceedings of the 15th International Symposium on the Packaging and Transportation of Radioactive Materials PATRAM, USA, 2007.
3. Sheldon, F. T. et al, "TRACKING RADIOACTIVE SOURCES IN COMMERCE", WM'05 Conference, Tucson, 2005.
4. Yu, W., et al "BASIC FACTORS TO FORECAST MAINTENANCE COST FOR NUCLEAR POWER PLANTS", 13th International Conference on Nuclear Engineering, Beijing, China, 2005.
5. Rautenberg, J.M. et al, "REMOTE STRUCTURAL DAMAGE DETECTION USING RADIO FREQUENCY IDENTIFICATION TECHNOLOGY", Advanced Technology, Japan, 2006.
6. Chen, I.R., and Gu, B., "A COMPARATIVE COST ANALYSIS OF DEGRADABLE LOCATION MANAGEMENT ALGORITHMS IN WIRELESS NETWORKS", British Computer Society, 2002.
7. Vajda, I. and Buttyan, L., "Lightweight Authentication Protocols for Low-Cost RFID Tags", Budapest University of Technology and Economics, Hungary, 2003.