LLNL-CONF-413229

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May 21, 2009

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Tucson, AZ, United States
July 12, 2009 through July 16, 2009

IMPLEMENTING NEW METHODS OF LASER MARKING OF ITEMS IN THE NUCLEAR MATERIAL CONTROL AND ACCOUNTABILITY SYSTEM AT SSC RF-IPPE: AN AUTOMATED LASER MARKING SYSTEM

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ABSTRACT
For over ten years SSC RF-IPPE, together with the US DOE National Laboratories, has been working on implementing automated control and accountability methods for nuclear materials and other items. Initial efforts to use adhesive bar codes or ones printed (painted) onto metal revealed that these methods were inconvenient and lacked durability under operational conditions. For NM disk applications in critical stands, there is the additional requirement that labels not affect the neutron characteristics of the critical assembly. This is particularly true for the many stainless-steel clad disks containing highly enriched uranium (HEU) and plutonium that are used at SSC RF-IPPE for modeling nuclear power reactors.

In search of an alternate method for labeling these disks, we tested several technological options, including laser marking and two-dimensional codes. As a result, the method of laser coloring was chosen in combination with Data Matrix ECC200 symbology.

To implement laser marking procedures for the HEU disks and meet all the nuclear material (NM) handling standards and rules, IPPE staff, with U.S. technical and financial support, implemented an automated laser marking system; there are also specially developed procedures for NM movements during laser marking. For the laser marking station, a Zenith 10F system by Telesis Technologies (10 watt Ytterbium Fiber Laser and Merlin software) is used.

The presentation includes a flowchart for the automated system and a list of specially developed procedures with comments. Among other things, approaches are discussed for human-factor considerations.

To date, markings have been applied to numerous steel-clad HEU disks, and the work continues. In the future this method is expected to be applied to other MC&A items.

INTRODUCTION

A nuclear material control and accounting system requires unambiguous and reliable identification of the accounting objects [1]. Furthermore, operational costs are reduced if the system can perform its functions relatively rapidly. Systems involving a human, i.e. an operator, are prone to errors related to human factors. These errors include mistakes in visual reading of indentifiers and in manual entry of data into accounting documents. Such errors lead to both lower confidence in the ability to account for nuclear material and increased costs associated with correcting the errors when they are discovered. It is also necessary to limit the radiation exposures received by operators performing accounting and technological activities with nuclear material (NM). This is a different side of the human factor, based on special properties of NM.

The specific radiation dose (D), defined as the radiation dose received by an operator when handling one accounting item, is proportional (as a first approximation) to the dose rate of the radiation source (M) and the time working with the accounting item (t), and is inversely propotional to the square of the distance (r) between the operator and the source. This can be expressed as: $D \sim f(M,t,1/r^2)$. It is easy to see that the specific dose can be reduced by decreasing the working time (t) for each accounting item and increasing the distance (r) between the accounting item and the operator.

Both human-factor errors and radiation exposure can be reduced by using automated item-identification technologies based on machine-applied and readable symbologies [2]. Such technologies also reduce opportunities for NM diversion.

When considering methods and means of applying indentifying marks on NM accounting items and containers, the first thing considered is the frequency of working with those items (whether they are stored in a vault or frequently used in experiments). Physical, geometrical, mechanical, temperature and radiation conditions must also be taken into account.

IPPE widely uses one-dimensional barcodes (Code 39, Interleaved 2 of 5) on adhesive labels attached to the surface of accounting items. During inventory taking barcode readers are used. For a large number of accounting items (mostly stainless steel-clad disks containing HEU used for modeling power reactors), the aforementioned marking methods are degraded by normal operations and become unreadable or are not applicable because their presence affects experimental parameters. Previously these items had been tracked by a hand-engraved identifying number on each disk. While this method could uniquely identify each disk, and disk locations were tracked with a database, inventory taking was tedious, error-prone, and subjected the operators to unnecessary radiation exposure. In order to reduce these problems, direct item-marking with machine-readable symbology was tested. Testing was proposed for the possibility of using two-dimensional symbology and several laser-marking technologies that applied symbols directly onto the items.

EVALUATION OF MARKING TECHNOLOGIES

Laser marking of Data Matrix ECC Level 200 [3] symbols was selected for evaluation. Data Matrix symbology is also capable of holding 25-100 times more information than typical barcodes. This range is directly related to the image quality, which is contingent on the specifications of the marking device as well as those of a reading device.

The following laser marking options recommended for use on metal surfaces were evaluated to determine the best applicable marking technology:

Laser coloring
Laser etching
Laser bonding
Laser Induced Surface Improvement (LISI)
Gas Assisted Laser Etching (GALE)

For testing, Data Matrix codes and human readable information were applied to samples of the stainless steel used for cladding uranium disks . Various size marks and systems from several manufacturers were evaluated. The marked test samples were evaluated for the quality of the mark as applied and after exposure to conditions typically encountered in technological operations performed on disks. The operational factors included:

Decontaminating solutions of two types;
Rubbing the marked sample surfaces against each other;
Three cycles of heating the samples to 80 C, 5 hour exposure at 80 C, cooling to ambient temperature, and checking readability. This was followed by one cycle of 5 hour exposure to 250 C and readibility checks.

The effects of marking on the integrity of the steel were also evaluated.

Two main conclusions from the testing [4] were:

- Laser coloring was the most appropriate technology for laser marking;
- For coding identification information, Data Matrix ECC level 200 symbology with an 8 x 8 mm matrix should be used. Human readable marks should also be applied.

AUTOMATED LASER MAKING SYSTEM FOR APPLYING MATRIX IDENTIFIERS

An automated marking system was warranted because of the nature of the materials (disks containing nuclear material), the necessity of a unique identifier for each item, and the difficulty associated with correcting mistakes should they occur during the marking process.

After the marking technology was chosen, a system vendor was selected, and the U.S. Project Team provided the following system: Telesis Technology - Zenith 10F (10 Wt diode Yb) fiber-laser marking system with diode focus control. This system comes with the Merlin – II LS 32-bit Visual Design Software, which is designed for generating an image (of matrix codes, among other things) to be applied to an item, for controlling the image parameters, and applying the image to the item.

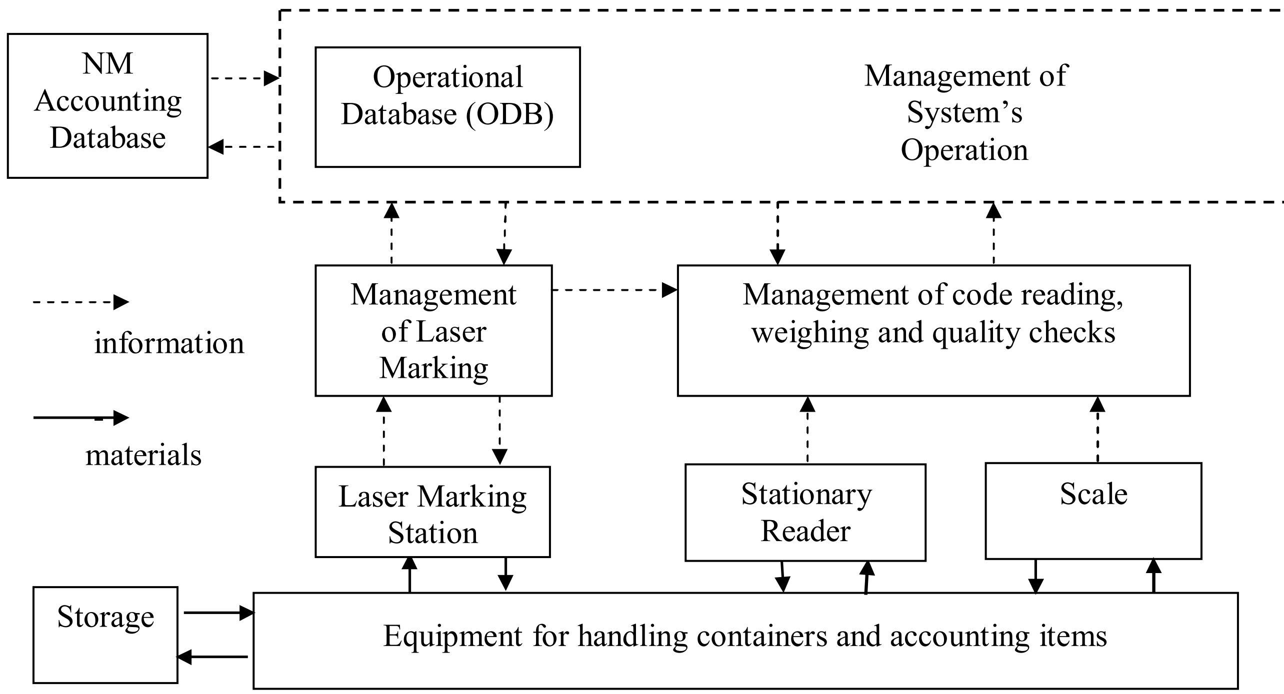
We first developed operational procedures and then test marked steel-clad NM disks and verified the correctness and quality of the marks. These procedures were incorporated into software that controlled marking and verification. The most important procedures are

Procedure for completing one shift of applying identifiers on disks.
Procedure for testing the control station equipment.
Procedure for testing the marking station readiness for operation.
Procedure for issuing NM to the place of marking operations and its return to the vault.
Procedure for preparing information and applying an image on a portion of each disk.

Procedure for image quality control and determining the gross weight of a disk.
Procedure for preparing reports for the tasks completed during a shift.

The corresponding software modules are written in the Microsoft Visual Basic 5.0.

A generalized functional diagram of the system is shown in Figure 1. Information (location, item number, and weight) for disks to be marked is extracted from the computerized NM accounting system and loaded into an operational database on the computer that controls the marking.



where

Laser Marking Station: Zenith - 10F Marking System by Telesis Technologies, Inc.
Stationary Reader: HawkEye 1510 for reading the Data Matrix code.
Scale: Mettler Toledo PB610.
Management Computers (2): HP Compaq d530 CMT with Pentium 4 (Windows XP)

Figure 1. Generalized functional diagram

Disks to be marked are brought to the marking location (Figure 2). As disks are positioned for marking the hand-engraved number on each disk is checked against the database. If the numbers agree, the disk is placed in a special tray that holds ten disks. These ten disks are marked as a batch with data matrix and human-readable codes (Figure 3).

Figure 2. Laser Marking Station. Laser and marking chamber are on the bench behind the control computer.

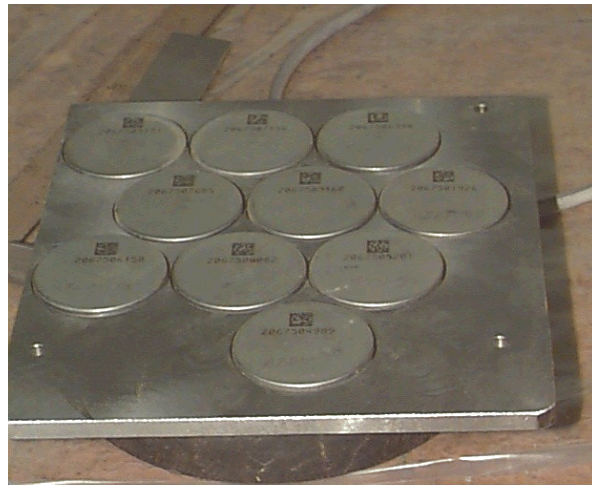


Figure 3. Tray of disks immediately after marking.

At the completion of marking, data for the 10 disks are sent to the control station computer. Marked disks are individually moved to a scale under a fixed matrix-code reader. The correctness and quality of the data matrix mark is electronically compared to the expected information and quality criteria. The weight of the disk is determined simultaneously and automatically compared to the weight in the database (Figure 4). If all tests are passed, the disk is returned to the container. Special procedures are in place to deal with outliers.

Figure 4. Verification station: scale, illuminator, and fixed reader.

CONCLUSIONS

The system has been in operation for a year with no major problems. Allowing for transfer of containers to and from the NM vault, operational personnel can mark about 250 disks during a 6 hour shift.

After all the marking is completed, scanners will be used to record movements and current locations of disks during technological operations, such as assembling the mock-ups of fuel assemblies and inventory taking, and to register the information in the nuclear material accounting database. Abandoning manual record keeping will reduce the number of mistakes by 3-4 orders of magnitude. The operator's time with an individual disk will be reduced by the factor of 2-3 with the respective reduction in the radiation dose rate. Besides, the unique marking technology will decrease the possibility of producing fake/imitation disks for NM disk substitution.

ACKNOWLEDGEMENTS

The authors express their appreciation to LLNL, BNL, and DOE for the financial and technical support of the project, and to the SSC RF IPPE operational personnel, where the described work was performed, for implementing the system and its vigorous operation. This work was performed under the auspices of the U.S. Department of Energy with the participation of Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and supported by employees of Brookhaven Science Associates, LLC under Contract DE-AC02-98CH10886 with the Department of Energy. LLNL and BNL signed contracts with SSC RF IPPE for performing this work.

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