ISTC Project No. 3534

"Creation of a Device for Detection of Explosives, Nuclear and Other Hazardous Materials in Cargo Containers and Luggage"

Summary of Technical Report

on the work performed from July 1, 2007 to June 30, 2010

Authorized for unrestricted publication

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Title of the Project: Creation of a Device for Detection of Explosives, Nuclear and Other Hazardous Materials in Cargo Containers and Luggage

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Detection of explosives, nanosecond neutron analysis, neutron generator.

Objectives / scope of work and technical approach / expected results

The main goal of this project is to develop, build and demonstrate the device for detection of explosive substances and fissile nuclear materials in cargo transport containers and luggage. This device (the “measurement module”) is based on Nanosecond Neutron Analysis (NNA) technique. NNA consists in detection and analysis of the secondary characteristic gamma and neutron radiation induced in the inspected object by 14 MeV neutrons in the spatial and temporal correlations with the activating neutrons. The method is position-sensitive, which allows one to obtain three-dimensional image of the elemental composition of the object.

The operation of the measurement module results in automatic elemental analysis of the contents of the container and three-dimensional spatial localization of the objects.

Obtained results

The following results were obtained in the framework of the ISTC Project #3534:

1. Prototype measurement module of a mobile device for detection of explosives and other hazardous substances and nuclear materials in shipping containers was designed, built and tested.
2. The prototype can automatically detect about 30 kg of hazardous substance hidden anywhere in the container in 5 minutes, using Nanosecond Neutron Analysis (NNA) technique.
3. In the same measurement the prototype can determine the location of the nuclear material in the container, using the principles of “tagged” neutron and gamma radiography (TNGR).

During the work on the project, some additional results were obtained that could be used for further development of hazardous materials detection methods:

1. A compact data acquisition system with digital signal processing was developed, which can be used in portable and mobile devices with the number of detectors from one to forty, and with one or several neutron generators.
2. A new type of gamma-ray detector with $LaBr_3$ crystal was tested, which can substantially improve the performance of devices based on NNA. Because of the relatively high cost of such detectors, their use is most appropriate in portable devices with a small number of detectors.
3. A new type of associated alpha-particle detector based on synthetic diamond with higher radiation stability than silicon detectors was tested. Such detectors can be used in neutron generators with long lifetimes of the neutron tube, such as pumped neutron generators.

During Project implementation the following Tasks and Subtasks were done:

Task 1.

Subtask 1.1.
In the frame of Subtask 1.1 a selective investigation of samples of domestic appliances and electronics has been performed in order to determine its average density. The sampling data give following values for good average density in transport packing: laundry washers – 0.22 g/cm^2, refrigerators – 0.13 g/cm^2, electric ovens – 0.15 g/cm^2, television sets – 0.075 g/cm^2. Maximal average filling density for 20-feet container is 0.59 g/cm^2.Carried out researches main characteristics of the cargo transported in cargo containers were defined.

Subtask 1.2.
In the framework of the Subtask 1.2 modeling of response functions for typical goods transported with sea cargo containers was carried out. Response functions for organic materials, food, domestic appliances and construction materials were calculated. These response functions were used in creating a library of training sets.

Subtask 1.3.
In the framework of the Subtask 1.3 methodological researches were carried out to determine the optimal parameters for neutron and gamma detectors. $LaBr_3$ showed better energy and time resolution as well as lower energy threshold. Researches proved detector based on $LaBr_3$ to be the most effective but due to high cost of such detectors it is still a trial to develop high efficiency measurement module. Due to the abovementioned reasons BGO-based detector was chosen. Plastic scintillator was chosen for neutron detectors.

Subtask 1.4.
The following results were received:

- Hidden sample at every chosen depth requires its own optimal geometry;
- Secondary gamma-ray detectors should be placed as close to “tagged” neutrons flux axis as possible, but not inside the area of the flux;
- At smaller depths, in case the depth increases, it is effective to move neutron generator off the container’s wall. That decreases background counting rate because the distance between neutron generator and secondary gamma-ray detectors increases;
- At bigger depths (more than 75 cm) to move neutron generator off the container’s wall is ineffective for the effect from a sample grows too small.

Subtask 1.5.

Considering carried out modeling and calculation procedures the list of main characteristics and components was prepared for a basic module for explosives detection inside cargo containers:

1. Basic module consisting of:
   a) neutron generator with built-in associated particles detector;
   b) 12 gamma-detectors based on BGO crystals;
   c) 3 neutron detectors based on plastic scintillator;
2. Control electronic package for neutron, gamma- and alpha-detectors.
3. Software for data-acquisition system and automatic decision-making system.

Modeling results received during implementation of the Task 1 were presented by A.V. Kuznetsov at 9th International International Conference on Applications of Nuclear Materials, 8-14 June 2008, Crete, Greece.

Task 2.

Subtask 2.1.
The segmented particle detector was developed, produced and tested in the framework of the Subtask 2.1 of the Task 2.

Subtask 2.2.
In the framework of the Subtask 2.2 neutron generator ING-27 was purchased. It was equipped with the associated particles detector which was tested inside the generator.

Subtask 2.3.
In the framework of the Subtask 2.3 associated particles detector’s electronics was developed and produced. Electronics was tested. As the second stage specific built-in software (DAQ) was developed.

Subtask 2.4.
In the framework of the Subtask 2.4 12 BGO modules, 3 plastic based, 1 LaBr3 and 1 NaI based modules were assembled and tested. All modules have one universal interface and are connected to the coincidence module. Electronic package for neutron and gamma detectors control and preliminary signal processing was developed. All detection modules were tested.

Subtask 2.5.
In the framework of the Subtask 2.5 of the Task 2 after works on production and assembling of the measurement module into the support frame (crates) a test prototype of the measurement module was produced. As a result of the performed works Basic Measurement Module User Manual was worked out.

Technical specification of the developed prototype was prepared “User Manual of the measurement module” (see Appendix 3 of the Final Project Technical Report).

Task 3.

Subtask 3.1.

In the framework of the Subtask 3.1 all earlier produced or purchased electronics modules were integrated into data acquisition system of the measurement module. Testing was carried out to tune the system elements for joint operation.

Subtask 3.2.
In the framework of the Subtask 3.2 algorithms of module control, data acquisition and decision making were developed for a singular module. Proposal was prepared with requirements for such kind of algorithms in general. All modules were tested for joint operation and tuned as components of the one system.

Subtask 3.3.
Configuration files were created, which contain parameters used by program to operate with different types of gamma-detectors: NaI, BGO and $LaBr_3$. Different stages of data acquisition and processing were tuned for better compatibility. Data acquisition algorithms using fast scanning of the container with radiographic methods were developed.

A possibility of joining adjacent 3D “voxels” has been added to the data analysis system in order to improve the spectral statistics. Many scenarios were developed to be used in various situations of detection of hazardous materials. These scenarios were tested in the framework of the Task 4. ” Measurement module software user manual” was worked out (see Appendix 4 of the Final Project Technical Report). Results were presented by Vakhtin D. N. at the International ISTC Workshop “*Non Proliferation* of *Weapons of Mass Destruction in Central Asia*” April 11-14, 2010 in Dushanbe, Tajikistan.

Task 4.

Subtask 4.1.
In the frame of the Subtask 4.1 the following results were obtained:

1. Intensity of the neutron generator with a built-in position-sensitive alpha-particle detector is 8×10^7 n/s in 4π.
2. BGO-based gamma-detectors can operate with load up to 2×10^5 s^{-1}. Higher efficiency level depends on temperature and PMT operation time. Thus, when using these gamma-detectors one needs to perform automatic energy calibration, which was realized in measuring module software.
3. Data acquisition system can operate jointly with ING-27, alpha-particle detector and 12 gamma-detectors with required output level.

Subtask 4.2.
In the framework of the Subtask 4.2 multi-functional model of the cargo container was produced. Measurements were taken in various geometries with one-sided and two-sided access using explosives imitator surrounded by innocuous materials.

Subtask 4.3.
In the framework of the Subtask 4.3 experimental measurement were carried out for the most typical cargo transported in sea cargo containers. A library of the training sets was created. To do that, measurements were made using neutron and gamma radiography methods. Investigations were made whether these two methods could be used simultaneously to get more particular information about container filling.

Subtask 4.4.

In the framework of the Subtask 4.4 experimental testing was carried out. Measurement module was capable to detect explosives imitator inside the cargo container model. Testing included measurements in one-sided and two-sided geometry with a hazardous material surrounded by innocuous materials. After testing was finished a Test Resport was worked out which was included in Final Project Technical Report (Section 3.3 Experimental Results, pp. 35-45).