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## ISTC Project Review Report:

# Radiation Sensors and their applications

June 2012

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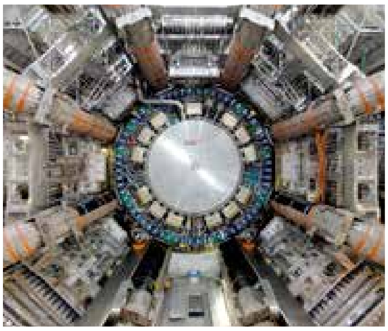

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## Executive Summary

Following the approval by the ISTC Governing Board (GB53) of a program to review the results of completed ISTC projects in identified scientific areas, an independent panel of international experts reviewed the results of ISTC funded projects for the area dealing with radiation sensors and their applications.

The Panel came to the overall conclusion that technologies were developed that can be used for the prevention of illegal trafficking of radioactive materials including nuclear materials accounting and control. Identified technologies with commercial potential can contribute for example to the work of IAEA in the field of nuclear safeguards.

Since sensors and detectors can often be more widely used there is the potential for applications in other sectors such as in the field of biomedical applications and to promote homeland security.

The funded work that contributed to the Large Hadron Collider experiments at CERN was of outstanding quality and fostered excellent collaboration between Russian and Western scientists.

While in most cases there was good value for money the Panel remarked that the project results require a better and broader mechanism of dissemination.

The report on radiation sensors and their applications has been published by ISTC. The publication can be downloaded from the ISTC website: www.istc.ru or can be ordered via e-mail to Mrs Elena Zaitseva of ISTC: zaitseva @istc.ru

## Introduction

The ISTC began its work as an international organization in 1994. More than seventeen years after the center opened its doors, the ISTC Governing Board (GB53) approved a program to review the results of completed ISTC projects for a number of scientific areas. This intergovernmental organization involves 39 nations and deals with cooperative science with a non-proliferation scope. The organization operates on the basis of the ISTC Agreement of 1992 and subsequent ISTC Governing Board decisions including the implementation guidelines.

During its many years of activity the ISTC has supported more than 2,715 civilian-oriented projects, which involved more than 90,000 scientists, engineers, and other technical personnel leading to more than 300 patents and numerous publications in prestigious international journals. The funding parties have contributed more than 850 million USD in support of ISTC projects. There was also an additional 170 million USD in supplemental (or additional support) programs. The research institutes and laboratories that have participated in ISTC projects also provided substantial in-kind resources. Thousands of collaborators from countries around the globe have played a role in ISTC projects and participated in ISTC conferences and workshops.

The topics decided by the Governing Board to be considered for reviews include, but are not limited to (i) nuclear safeguards (safety, security and related issues); (ii) radiation sensors and their applications; (iii) technologies to support oil and gas research; (iv) research to support energy requirements (renewable energy, energy storage, energy transmission) and (v) bio-medical applications (resulting from nuclear research).

An operational guide was established outlining the procedures and the approach to be applied to this ISTC review of the results of the work performed by ISTC (see Annex 1).

The present report describes the results of the review of ISTC projects in the field of radiation sensors and related issues.

## Approach

### The Review Panel

A Panel was established to review the results of completed ISTC projects dealing with "Radiation Sensors and their Applications". The individual experts and the chairperson were selected by the Secretariat in close consultation with the sponsoring parties/partners. This Panel was chaired by Prof. Henry H. Mantsch, Senior Science Advisor, Global Partnership Program, Foreign Affairs and International Trade Canada and Canadian SAC member, being supported by Dr. Igor Zakharchenko, Senior Coordinator to the ED, acting as the Secretariat.

*The Review Panel meeting of 28-29 February 2012*

The other participants in the Panel were:
Dr. Marco DiCapua, Chief Scientist, Defense Nuclear Non-Proliferation Research and Development, National Nuclear Security Administration, USA

Dr. Peter E. Vanier, Technical Advisor, Advanced Materials Program, Nonproliferation and Verification R&D, Office of Defense Nuclear Nonproliferation, National Nuclear Security Administration, USA

Prof. Dr. Voloshin Nikolai Pavlovich, Director and Adviser of Russian Federal Nuclear Center, VNIITF, Snezhinsk, Russia

Dr. Ivanin Igor Alexandrovich, Head of the Department of VNIIEF, Sarov, Russia.

Dr. Rusakovitch Nikolai Artemevich, Deputy Director, Scientific Chief Scientific Secretary, JINR, Dubna, Russia.

Prof. Dr. Peter Senger, Section Head GSI Helmholtzzentrum fuer Schwerionenforschung GmbH, Darmstadt, Germany.

## THE REVIEW PROCESS

The review process comprised the following steps:
1) Identification of the scientific areas to be reviewed
2) Selection of relevant projects per identified scientific area
3) Preparation of a draft review report
4) Discussion of the report by the Review Panel
5) Adoption of the report by the ISTC Governing Board
6) Publication and dissemination of the report.

Only funded projects that started after 1 January 2001 and are now technically complete were selected for this particular scientific sector.

Annex 2 provides the list of projects reviewed for this sector. It contains the most relevant project information (i.e. the project number, title, lead institute, funding received, period of work).

20 out of the 35 projects were identified for oral presentation but only 7 of these were actually presented to the Panel, the others had to be dropped due to the unavailability of project managers. The Panel deplores this fact.

At the same time, the Panel would like to thank those who made the effort to come and make presentations:
- Mr. Fakhroutdinov R. M., # 1639 Tracking System for "Atlas" Institute for High Energy Physics, Protvino;
- Mr. Andreev I. I., #1559 Aerocomplex for Radiation Monitoring VNIIEF, Sarov;
- Mr. Shevelev A. E., #3785 Fast Gamma-Ray Spectrometry, Physical Technical Institute, St Petersburg;
- Mr. Tarkovsky E. I., #3090 Calorimeter modules for new generation colliders ITEF (ITEP), Moscow;
- Mr. Larionov P. V., #1954 Fissile Materials Identification Device, All-Russian Research Institute of Automatics;
- Mr. Samosadny V. T., #1644 Nuclear Materials Identification MIFI, Moscow;
- Mr. Romodanov V. L., # 2978 Digital Technology for Fissile Materials Detection MIFI, Moscow.

The presenters provided an excellent overview of the research results and responded fully to the questions raised by Panel members.

## THE SCORING SYSTEM

An evaluation scoring system was used by the Panel to provide an independent review of the selected sector projects. This scoring system is based on an evaluation system developed by the Scientific Advisory Committee (SAC) of ISTC. The final technical report, the project assessment sheet and the foreign collaborators assessments were the main sources of information for the completion of the evaluation sheets (see Annex 3). Oral presentations provided additional information which was considered quite useful but the Panel members in the final discussion on the outcome of their review agreed that they did not introduce a negative bias for those projects which had only written information available.

All selected projects were evaluated on the basis of the following criteria:
1) Accomplishment of major tasks of the project, to include degree of fulfillment of project work, achievement of final objectives and cost efficiency of the project
2) Contributions to the scientific field in question
3) Impact of the results of the project, i.e. did it lead to further applied research, commercialization of new technologies, innovation in existing technologies or patents?
4) Dissemination of project results which includes publications in international and national journals and presentations at international conferences
5) Collaboration network between CIS institutes
6) Partnership and collaboration with foreign institutes.

Within each criterion, the averaging of ratings given to subcritera was left to the individual Panel member. The Panel agreed that criterion 3 related to impact was particularly important for this review exercise which is clearly more than just a financial and scientific audit. In several cases, the criterion related to the collaboration between CIS institutes was less relevant because in the past networking among institutions of the CIS suffered from excessive compartmentalization; on the other hand, in the nuclear sector the projects were conducted in very large research entities such as Sarov where existing competencies range from pure science to manufacturing of components, making networking superfluous. This aspect was taken into account when scoring criterion 5.

For their evaluations the Panel members noted the role of the time factor, considering the long time span between the initiation of some of the early projects and the completion of the latest projects. This has two implications: firstly, the science used in some early projects could appear now obsolete or at least routine while it was cutting-edge at the time of the conduct of the project; secondly, the projects funded within the ISTC framework gradually shifted from good science to the applications of science; this evolution was taken into account when scoring criterion.

## Results of reviewed projects

Annex 4 summarizes the overall scores given by each of the 7 Panel members and the consensus score the Panel reached for each of the reviewed 35 projects. This table shows a good convergence of the ratings from the individual Panel members, in spite of their different scientific backgrounds. The reviewed projects can be divided into three groupings (see Annex 5):

1) Detectors in high energy physics
2) New sensors development
3) Detector systems.

### Project 822: Multichannel Clinical Dosimetry

Under this project a concept for hardware for measurement of radiation was developed. Since only a system for clinical dosimetry was developed the project received a low score.

### Project 1246: Nondestructive Burnup Measurements

This project developed parts of a technique to measure spent fuel burn-up depth for RBMK-type reactors. While the project is of significance given the outstanding fuel inventories in RMBK reactors, the outcome was unclear as there was no comparison between the spectrometry results and a destructive analysis of the fuel that revealed the actual burn-up depth. The project received therefore a low score.

### Project 1559: Aerocomplex for Radiation Monitoring

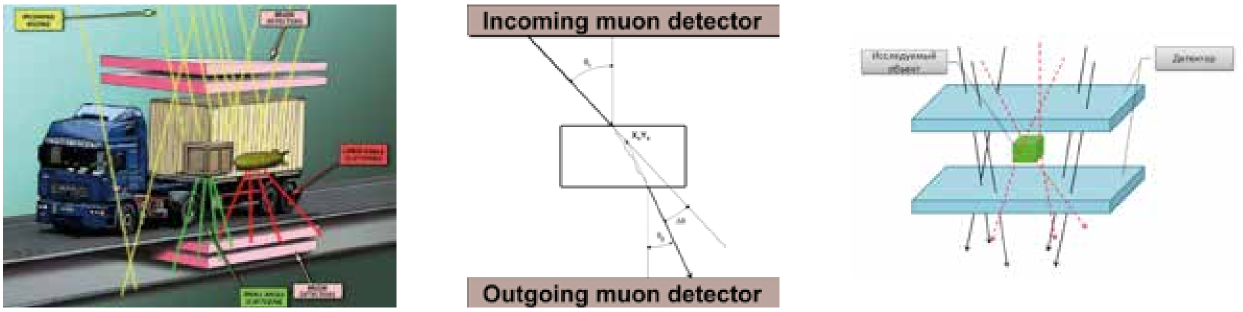
The project is of interest from the standpoint of its potential application within the system of inspections at non-declared nuclear facilities/testing sites and for the examination of locations where accidents took place with radiation.

*# 1559: One of the layout options of the multidetector spectrometer module.*

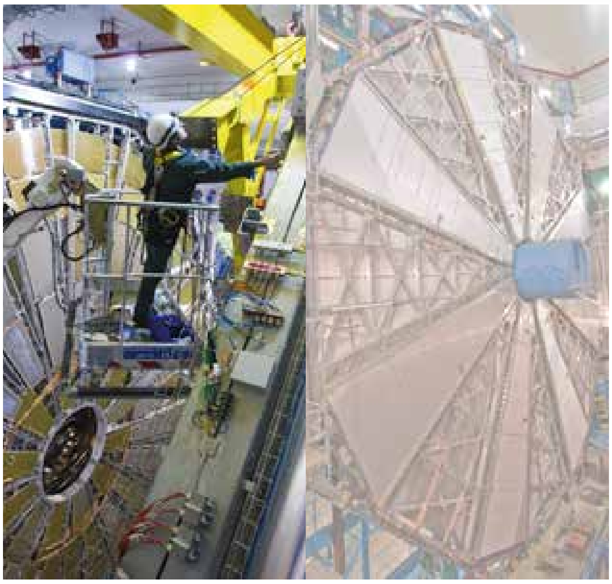
*# 1559: Setting up of the equipment prior to the measurement.*

### Project 1639: Tracking System for ATLAS

The development and construction of a substantial part of the muon tracking chambers for the ATLAS experiment posed a major technological and managerial challenge to the participating institutes IHEP Protvino, JINR Dubna, and VNIITF Snezhinsk. IHEP produced 254 large area chambers (3 to 7 m$^2$) comprising 76,000 high precision detection tubes. JINR constructed 36,000 drift tubes. VNIITF designed and constructed the support structure for the detectors. All components were installed into the ATLAS experiment and performed as foreseen. The technology was applied in the design of large-area scanning devices for containers. The project was highly successful.

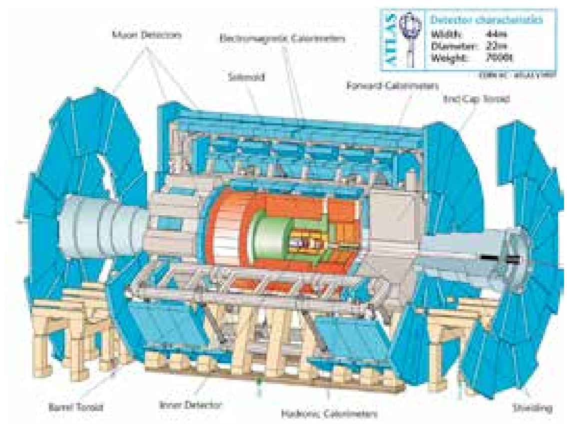



*# 1639: Application of drift tube chambers for cosmic muon tomography. Using of multiple Coulomb scattering of cosmic ray muons is an attractive way for detection of hidden materials.*



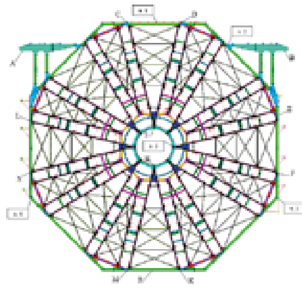
# 1639: ATLAS muon chambers assembly

# 1639: Automatic chamber glueing machine. Chamber spacer. Glued chamber at the granite table.




*# 1639: Detector ATLAS (LHC, CERN, Switzerland), IHEP (Protvino): 254 MDT chambers (76 000 drift tubes), JINR (Dubna): 96 MDT chambers (36 000 drift tubes), VNIITF (Snezhinsk): Conceptual design of large support frames.*

*General view of the Big Wheel designed by RFC-VNIITF.*



*Finite element model of MDT wheel (RFC-VNIITF)*

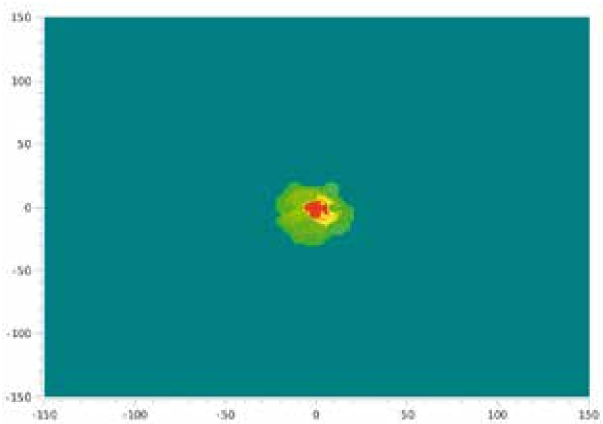



*Photo and tomographic image of depleted uranium (1 min).*

## Project 1644: Nuclear Materials Identification

The main value of this project was a detailed review of applications for the prevention of illegal trafficking of radioactive materials.

## Project 1800: End-cap ATLAS Tracker

The manufacturing, assembly, and testing of the end-cap Transition-Radiation Tracker (TRT) for the ATLAS experiment was performed by a consortium consisting of MEPhI, PNPI, JINR, and the company Mashinostroitel in Perm. The complete technology of the ATLAS TRT including the straw tubes, parts of the read-out electronics, mechanical support structure and the gas supply and purification system was developed by Russian institutes. Moreover all necessary simulations and calculations were performed and also the final tests. The TRT is an essential part of the ATLAS experiment at CERN and contributed successfully to the data taking. The set forth objectives of the project were met.

## Project 1834: Portal Detectors for Nuclear Materials

The objective of the project was to develop a new photomultiplier (PMT) with a very elongated geometry, suitable for coupling to large area scintillators used in portal monitors that detect the passage of radioactive materials. The advantage over traditional PMTs was shown in increased sensitivity at the low energy part of the gamma spectrum, because of improved light collection.

## Project 1933: Remote Detection of Alpha Pollution

The developed instrument prototype developed here can serve to improve commercial detectors for measuring alpha-radioactive contamination of surfaces. According to its designers the detector could also be modified to detect pollution in liquid environments.

## Project 1954: Fissile Materials Identification Device

This project has developed a very specialized instrument for the inventory of nuclear materials, combining a bar code system visible on the outside of a container with gamma spectroscopy to confirm the materials inside. The technology developed here has the potential for further optimization and practical applications. The experimental work to identify plutonium and the technology and related equipment could be recommended for integration in the nuclear materials accounting and control activities implemented by IAEA.

*# 1954: Russian rapid inventory confirmation system (RICS)*

*# 1954: New analyzer VESTA-K*

## Project 1956: Database on Silicon Nuclei Fragmentation

This project is an excellent example for a small efficient and thorough nuclear physics experiment with important applications, i.e. for the use of microelectronic devices in space missions. The systematic measurement and documentation of the fragmentation cross sections of silicon nuclei when bombarded with protons and deuterons provides a database for so called single-event upsets which limits the functionality of highly integrated electronics in laboratory experiments and in satellites. Moreover, the project developed a theoretical description based on Monte-Carlo transport models which reproduce the data and hence, have a predictive power to extrapolate the results into unmeasured energy domains. The ISTC project 1956 was very successful.

### Project 1999: Inner Tracker and Multiplicity Detector for the ALICE Experiment

The focus of the project was the design, production and test of the carbon fiber lightweight space frames for the inner tracking system of ALICE, of a full scale model for the ladders which carry the silicon sensors, and a full scale detector model with liquid and air cooling. Moreover, a prototype for a forward multiplicity detector has been manufactured. The project had a major impact on the development and construction of ALICE in spite of the very limited budget available. The work within this project developed a concept for a modern tracking detector system that avoids multiple scattering.

### Project 2134: Thermal Analysis for ATLAS Detector

In general, the project objectives were fulfilled. The results of the completed calculations were essential to the success of the ATLAS detector. Calculation methodologies exercised in the project are applicable for future ATLAS experiments.

### Project 2283: Diamond Spectrometers and Dosimeters

The scope of this project was to demonstrate considerable potential for the development and practical applications of diamond spectrometers and dosimeters.

### Project 2353: Development of Intelligent Detectors for Automated Regional Monitoring of Emergency and Ecological Situation

The scientists worked effectively at integrating contemporary technology into remote sensors for environmental studies using a gas correlation infrared radiometer.

### Project 2500: Calibration of the Space Solar Patrol

The aim of this project work was to integrate the results of three earlier ISTC Projects (Projects 385, 385-2, 1523) which all had received high international ratings. The equipment developed within the project can serve as a method for designing a metrological system for a broad spectrum of applications.

### Project 2503: Research and Development of High Sensitivity Semiconductor Sensors for Gases and Ionizing Radiation for Environmental Monitoring

Solid state sensors for gases and radiation were already text book science when this project was initiated. The review done in this project could not establish the originality of the research and development. However, the project was useful for capacity building at a number of Russian institutions.

### Project 2637: Nuclear Materials Detection by Photoneutrons

This was a very thorough and detailed study of a variety of active interrogation techniques that may be useful in the scanning of cargo for concealed nuclear materials. This research group could help to establish practical methods of cargo scanning at sea ports. A photoneutron technology for nuclear material detection was tested under laboratory conditions and various options for its optimization were developed. A concept of nuclear material detection was developed for physical protection systems at nuclear facilities and at customs control points.

### Project 2719: The LHCb Hadron Calorimeter

The goal of this project was to manufacture 86,000 scintillation tiles and 50 steel modules for the hadron calorimeter. More than 200 integrated electronic modules and control units for calibration purposes were developed and produced. This ISTC project provided an important contribution to the LHCb experiment at CERN.

### Project 2732: Search for Neutron Source in Urban Areas

The project was an exercise in system integration of neutron detectors and a global positioning system, for use in searching for a neutron-emitting radioactive source such as plutonium. The system was strapped to a person, and was successful in recording on a map the location of the moving detector as well as its signal intensity. The science was not new, but the engineering is relevant to nonproliferation. The device could be of interest to the IAEA.

## Project 2728: Radiation Detectors on Base of TlBr Crystal

The study of semiconducting thallium bromide material for using in gamma spectrometers is an active area of research around the world. The project included material synthesis, crystal growth and extensive characterization of electrical properties, as well as prototype detector fabrication. Unfortunately, this material has been found to suffer from mobile defects which cause the properties to change with time under an applied electric field. The work could be continued to explore better methods of purification, dopant additions, and contact preparation that may mitigate electromigration and polarization.

## Project 2880: The Start Detector for the ALICE Experiment

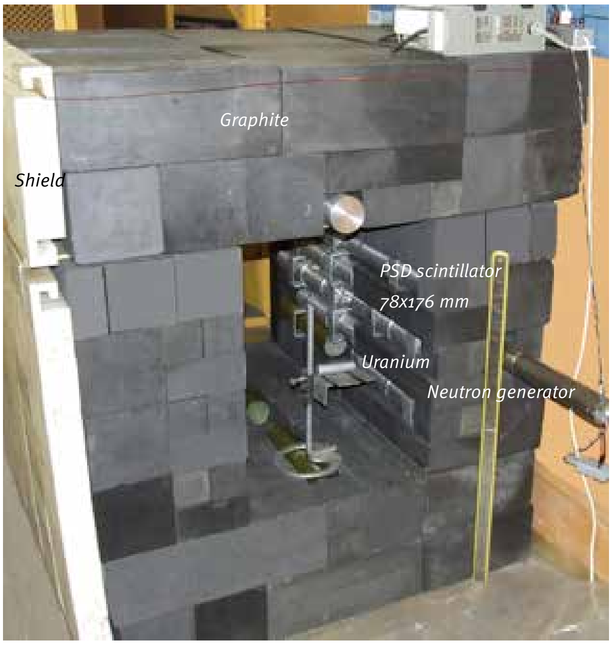
The aim of the project was to design and to build a time-of-flight start detector for the ALICE experiment at the LHC. The detector is based on two circular arrays of quartz Cherenkov counters surrounding the beam pipe and measuring the fission products. The light is read out by Russian photomultiplier tubes which can be operated in magnetic fields of up to 0.5 Tesla. The project included the design of the detector by detailed Monte Carlo simulations, and the development of the data read-out and control system. The start detector worked very successfully in experimental conditions and played an important role in the data analysis at CERN.

## Project 2978: Digital Technology for Fissile Materials Detection

An approach was developed combining physical methods of detection of explosives and fissile materials and digital modalities of real-time detector data processing.

## Project 3024: Semiconductor Coordinate-Sensitive Detectors

The proposed 2D pixel detector matrices were used for the detection of α-particles and electrons in the space experiments. Matrix applications in customs control instruments or medical tomography are possible. The researchers performed “heroic” work in semiconductor design and implementation using old worn-out equipment. Follow-up projects are hardly possible due to the lack of a well-developed semiconductor industry in Russia.

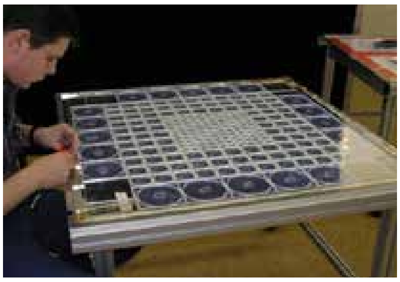




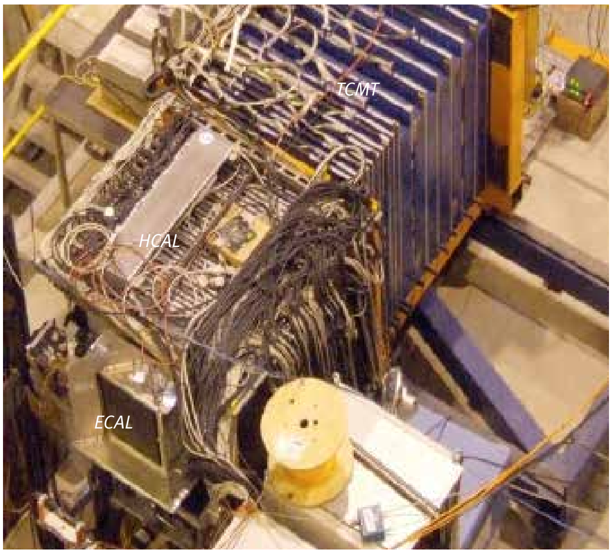
*# 2978: Count of time coincidences of FM particles by PSD EJ-309 scintillators and digital technology*

## Project 3090: Calorimeter Modules for a New Generation of Colliders

A calorimeter module prototype was built which comprised 38 detecting planes of scintillating tiles interleaved by 22 mm thick stainless steel absorber. More than 10000 photomultipliers were manufactured and tested. The Hadron Calorimeter was constructed, commissioned and operated for a number of years at CERN. This project had a significant impact on the work performed at CERN and laid the base for further R&D on hadron calorimetry.



*38 planes*



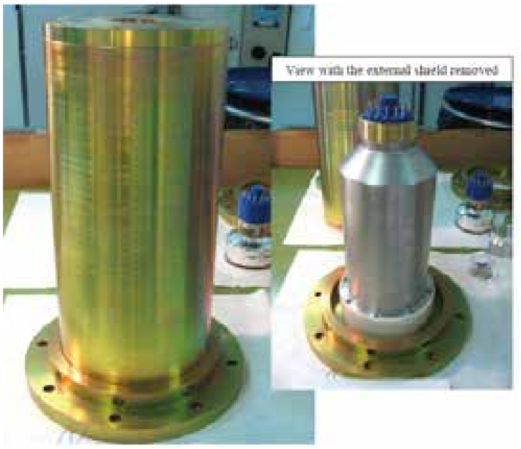

*#3090: Calorimeter prototype*

## Project 3667: Nuclear Materials Detector

Insufficient information was provided on this project to perform a review.

## Project 3785: Fast Gamma-Ray Spectrometry

The technique and instruments developed for the spectrometry of high-energy gamma-rays from nuclear plasma reactions was tested successfully at the JET Tokomak. The project has great potential but needs further optimization. The technique and instruments developed for the spectrometry of high-energy gamma-rays from nuclear plasma reactions was tested successfully at the JET Tokomak. The project has great potential but needs further optimization.




*# 3785: The detector is supplied with an iron housing protecting the detector against magnetic fields and a LED system of crystal illumination for PMT gain monitoring.*

## Project A-1165 LuAP Scintillation Crystals for New Generation Positron Emission Tomography

This was a rather ambitious project that had a good chance of success but depended on the skill of the crystal grower. Unfortunately the quality of the ingredients compromised the quality of the crystal detectors. The investigators demonstrated good discipline in publishing the results they obtained.

## Project G-646: Selective Detectors for Nuclear Radiation

Positive results were obtained in the detection of fast neutrons against an interfering γ-radiation background, however the selective detection of γ-beams against neutron radiation was not fully achieved.

### Project G-1160: Nanocrystalline Scintillators

The project performed extensive research and development on producing nanopowders of oxide compounds including lutetium silicates, titanates and aluminates that were then consolidated by plasma sintering and hot pressing to form scintillating materials. Extensive data was generated and published on x-ray crystallography as well as some data on absorption and emission spectra. These materials are potentially useful for medical imaging, for example in Positron Emission Tomography detectors. However, it is not apparent that the work advanced to the stage of producing high quality scintillators capable of x-ray or gamma-ray counting with reasonable energy resolution. While sintered materials are expected to be produced at lower cost than single crystals, these scintillator performance is not yet competitive with the commercial state of the art.

### Project T-1157: Modeling of Gadolinium-Based Neutron Converter

The project studied a neutron detector consisting of thin gadolinium foils arranged in layers within a gas volume. 1 mm holes penetrated the foils with a pitch of 2 mm. Gamma rays emitted in the Gd-neutron absorption process release electrons that drift through the apertures of the foils which themselves are step-wise biased to high voltage. The project carried out extensive modeling calculations of the neutron absorption, electron emission, avalanche amplification and electron collection. They also produced a prototype where they carried out some preliminary measurements. The authors published their results extensively.

### Specific Comments (for those interested in a detailed analysis of the projects)

The projects 1639, 1800, 1999, 2134, 2719, and 2880 which are all related to the LHC experiments ATLAS, ALICE, and LHCb, fostered a highly productive collaboration between Russian and other physicists regarding the development and construction of the largest and most advanced high-energy accelerator experiments worldwide. All projects have been completed successfully, and the delivered detector components met the specifications. In conclusion the ISTC projects have provided an extraordinary opportunity for physicists and engineers from Russia to contribute their unique skills to the design and implementation of extraordinary complex detectors. These ISTC-funded projects effectively incorporated Russian physicists and engineers into mainstream activities of the international scientific community. These activities thus acquainted Russian research institutes with world-class science technological standards. These ISTC projects set an excellent foundation for further collaborations which have been started already in several cases.

## Conclusions

- The main conclusion of this review is that for the projects funded in the area of radiation sensors, the overall objectives of ISTC were achieved. There was good value for money, proper project management as well as high-quality collaborations both nationally and internationally. Details appear in the previous section.
- The funding of projects in this particular field triggered important developments in the area of radiation sensor development.
- It has to be emphasized here that ISTC's financial support played a key role in the realization of the scientific tasks at hand. Good engineering work was performed. In some cases other organizations such as Rosatom continued to provide financial support in order to ensure follow-up of the initial work performed with ISTC funding.
- The institutional framework of ISTC brought scientific communities together and thus connected Russian scientists with their peers elsewhere in the world. A contribution was made to the overriding goals of the policy of non-proliferation (responsible science management; inspection; detection; monitoring and control).
- The results of some (regrettably only few) projects led to patents that were filed under the law of the Russian Federation.
- Some of the completed ISTC projects are now seeking additional funding from other organizations such as Skolkovo.
- In particular the high energy physics projects 1639, 1800, 1999, 2134, 2719, and 2880 stand out. The Panel members remarked that these projects provided a major contribution to the muon detectors for the ATLAS system at the Large Hadron Collider in CERN.
- ISTC funding for these high energy physics activities provided a major opportunity for scientists from the FSU nuclear weapons laboratories to engage with world-class "Big Science" outside of their confined world in a manner and style that was unimaginable before the founding of ISTC.
- The Panel recognizes the future of the scientific and technological endeavors funded by ISTC depend heavily on policy and economics rather than on scientific and technical issues. From this viewpoint, it is unlikely that most of the R&D carried in this area will spawn new, thriving or even self-sustaining industrial spin-offs that can survive without government support.
- The review revealed that many of these projects have a long way to go (both time and funding) before they can produce and market a product at a profit.

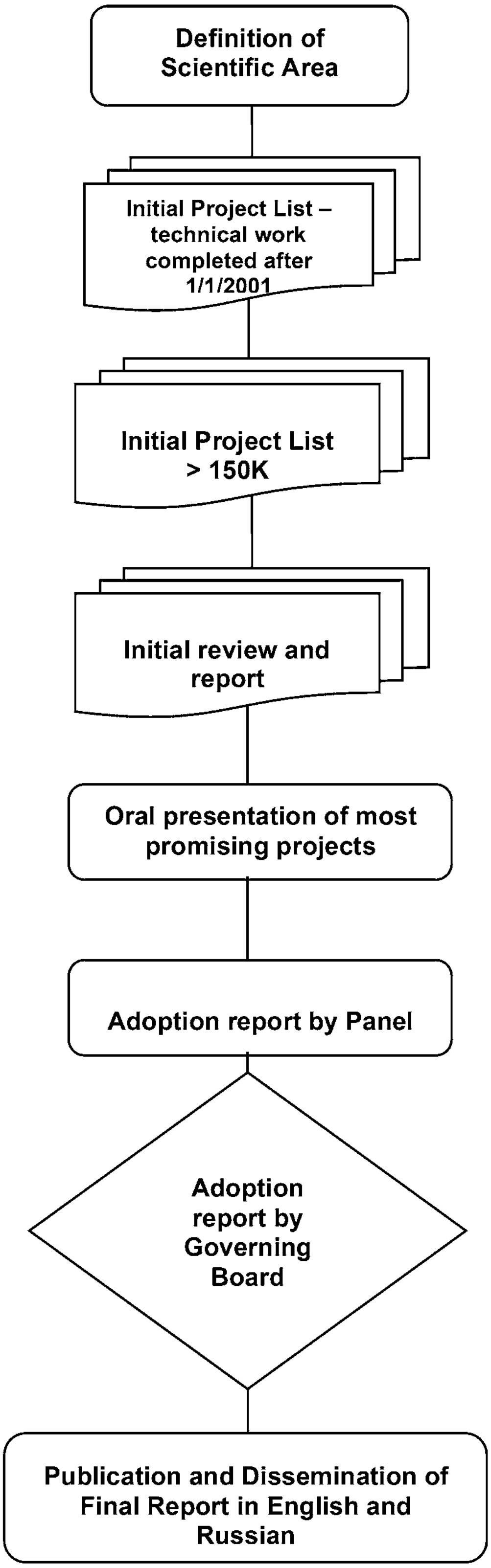
- Some, however, have shown they can satisfy a niche for unique equipment that scientific research or national security requires, but they do not lead to products appropriate for the consumer market.
- Others can be used more widely. Thus there is good potential for their employment in other sectors such as in the field of biomedical applications and to promote homeland security if and when market conditions are appropriate.

## Recommendations

- Thus, the Panel recommends that ISTC improve the external relations component regarding the work funded so that the project results receive a better and broader dissemination.
- The Panel recognizes that future cooperation on basic research is a definite possibility, provided that there is a convergence of mutually beneficial interests that will lead to local (as opposed to grant or contract-based) funding of activities.

# ANNEXES

## Annex 1. ISTC Project Review Process Flow Chart



# Annex 2. Projects Reviewed

| No | Short title | Leading Institute | Funds | Start | End | Duration (year) |
|---|---|---|---|---|---|---|
| 822 | **Multichannel Clinical Dosimetry** | NIIIT (Pulse Techniques), Moscow, Russia | **$271,717** | 01.07.01 | 01.12.04 | 3 |
| 1246 | **Nondestructive Burnup Measurements** | Khlopin Radium Institute, St Petersburg, Russia | **$360,000** | 01.03.01 | 01.08.03 | 2 |
| 1449 | **Safe Transportation of Excess Plutonium** | VNIITF, Snezhinsk, Chelyabinsk reg., Russia | **$400,000** | 01.01.01 | 01.06.04 | 3 |
| 1559 | **Aerocomplex for Radiation Monitoring** | VNIIEF, Sarov, N. Novgorod reg., Russia | **$225,000** | 01.09.01 | 01.10.04 | 3 |
| 1639 | **Tracking System for «Atlas»** | Institute for High Energy Physics (IHEP), Protvino, Moscow reg., Russia | **$1,217,220** | 01.06.01 | 01.06.10 | 9 |
| 1644 | **Nuclear Materials Identification** | MIFI, Moscow, Russia | **$355,000** | 01.06.01 | 01.12.02 | 2 |
| 1800 | **End-cap ATLAS Tracker** | MIFI, Moscow, Russia | **$2,048,000** | 01.07.00 | 01.04.06 | 6 |
| 1834 | **Portal Detectors for Nuclear Materials** | NIIIT (Pulse Techniques), Moscow, Russia | **$150,000** | 01.05.03 | 01.11.04 | 2 |
| 1933 | **Remote Detection of Alpha Pollution** | NIIIT (Pulse Techniques), Moscow, Russia | **$215,870** | 01.09.02 | 01.09.04 | 2 |
| 1954 | **Fissile Materials Identification Device** | All-Russian Research Institute of Automatics, Moscow, Russia | **$220,000** | 01.02.02 | 01.05.04 | 2 |
| 1956 | **Database on Silicon Nuclei Fragmentation** | Khlopin Radium Institute, St Petersburg, Russia | **$234,700** | 01.01.03 | 01.04.06 | 3 |
| 1999 | **Inner Tracker and Multiplicity Detector for «Alice» Experiment** | TsKBM, St Petersburg, Russia | **$80,325** | 01.03.02 | 01.08.03 | 1 |
| 2134 | **Thermal Analysis for ATLAS Detector** | State Unitary Enterprise STRELA, Snezhinsk, Chelyabinsk reg., Russia | **$173,000** | 01.05.02 | 01.05.04 | 2 |
| 2283 | **Diamond Spectrometers and Dosimeters** | TRINITI, Troitsk, Moscow reg., Russia | **$300,000** | 01.04.04 | 01.04.08 | 4 |
| 2353 | **Intelligent Detectors for Emergency and Ecological Monitoring** | Research Institute of Microelectronics «Progress», Moscow, Russia | **$298,000** | 01.03.03 | 01.07.06 | 3 |
| 2500 | **Calibration of the Space Solar Patrol** | Budker Institute of Nuclear Physics, Akademgorodok, Novosibirsk reg., Russia | **$208,994** | 01.08.04 | 01.08.07 | 3 |
| 2503 | **Gas Sensors and Radiation Detectors for Monitoring** | Russian Academy of Sciences / Institute of Radioengineering and Electronics / Fryazino Branch, Fryazino, Moscow reg., Russia | **$449,809** | 01.03.04 | 01.03.07 | 3 |
| 2584 | **Reactivity Evaluation Device** | VNIIEF, Sarov, N. Novgorod reg., Russia | **$295,551** | 01.01.05 | 01.06.07 | 2 |
| 2637 | **Nuclear Materials Detection by Photoneutrons** | Kurchatov Research Center, Moscow, Russia | **$141,000** | 01.12.04 | 01.12.06 | 2 |
| 2714 | **Detection of Explosives by the Gamma-Activation Method** | VNIITF, Snezhinsk, Chelyabinsk reg., Russia | **$30,000** | 01.09.04 | 01.09.05 | 1 |
| 2719 | **The LHCb Hadron Calorimeter** | Institute for High Energy Physics (IHEP), Protvino, Moscow reg., Russia | **$240,200** | 01.10.03 | 01.08.08 | 5 |
| 2728 | **Radiation Detectors on Base of TlBr Crystal** | Institute of Physical-Technical Problems, Dubna, Moscow reg., Russia | **$276,000** | 01.12.04 | 01.06.07 | 2 |
| 2732 | **Search for Neutron Source in Urban Areas** | NIIIT (Pulse Techniques), Moscow, Russia | **$202,950** | 01.12.04 | 01.12.06 | 2 |
| 2880 | **Start Detector for ALICE Experiment** | Russian Academy of Sciences / Institute of Nuclear Research, Moscow, Russia | **$289,239** | 01.06.05 | 23.05.07 | 2 |
| 2978 | **Digital Technology for Fissile Materials Detection** | MIFI, Moscow, Russia | **$435,891** | 01.10.05 | 01.09.08 | 3 |
| 3024 | **Semiconductor Coordinate-Sensitive Detectors** | Russian Academy of Sciences / Institute of Nuclear Research, Moscow, Russia | **$260,000** | 01.02.07 | 01.08.09 | 2 |
| 3090 | **Calorimeter Modules for New Generation Colliders** | ITEF (ITEP), Moscow, Russia | **$426,720** | 01.05.05 | 01.05.07 | 2 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 3534 | **Device for Detection of Explosives** | Khlopin Radium Institute, St Petersburg, Russia | **$515,249** | 01.07.07 | 01.07.10 | 3 |
| 3667 | **Nuclear Materials Detector** | Russian Academy of Sciences / Physical Technical Institute, St Petersburg, Russia | **$665,000** | 01.04.07 | 01.10.09 | 3 |
| 3785 | **Fast Gamma-Ray Spectrometry** | Russian Academy of Sciences / Physical Technical Institute, St Petersburg, Russia | **$48,000** | 01.12.07 | 01.06.10 | 3 |
| A-1165 | **Scintillators for Positron Emission Tomographs** | Institute for Physical Research, Ashtarak-2, Armenia | **$256,000** | 01.08.05 | 01.02.08 | 3 |
| A-1292 | **Converters and Detectors for X-Ray Imaging** | A.I. Alikhanyan National Science Laboratory, Yerevan, Armenia | **$261,124** | 01.12.06 | 01.12.10 | 4 |
| G-1160 | **Nanocrystalline Scintillators** | Georgian Technical University, Tbilisi, Georgia | **$289,239** | 01.07.05 | 01.07.08 | 3 |
| G-646 | **Selective Detectors for Nuclear Radiation** | Scientific-Research Institute of Automatic Systems «Skhivi», Tbilisi, Georgia | **$286,000** | 01.04.02 | 01.07.05 | 3 |
| G-982 | **Detectors Based on Cherenkov Effect for NPP Safety** | Tbilisi State University / High Energy Physics Institute, Tbilisi, Georgia | **$250,000** | 01.04.05 | 01.10.08 | 4 |
| T-1157 | **Modeling of Gadolinium-Based Neutron Converter** | Physical-Technical Institute, Dushanbe, Tajikistan | **$309,857** | 01.06.05 | 01.09.08 | 3 |

The abstract and other unrestricted information per selected projects are available at the ISTC Secretariat upon request.

# Annex 3. Evaluation Form for Technical Review of ISTC Projects

| | |
|---|---|
| This evaluation form will be completed on the basis of written evaluations:<br>Final Technical Report,<br>Project Assessment Sheet,<br>Foreign collaborators approval/assessment, and the oral presentations to the panel. | |
| Project Attributes | |
| Project Number | |
| Project Title | |
| Leading Institute | |
| Project Manager | |
| Foreign Collaborators | |
| Duration | |
| Total Budget | |
| Funding Parties | |
| ISTC Project Manager | |

| | |
|---|---|
| Evaluation of Completed Project | |
| I. Accomplishment of major tasks of the project | |
| Degree of fulfillment of scientific objectives<br>i.e. were the foreseen research objectives fully met, partially met, or not met at all? | (A, B, C)* |
| Degree of fulfillment of other objectives<br>i.e. non-proliferation, human engagement, sustainability. | (A, B, C) |
| Cost efficiency of the project<br>i.e. were the project costs in line with the project activities – was there value for money inside the project? | (A, B, C) |
| Comments | |

| | |
|---|---|
| Average score of I | (A, B, C) |
| II. Contributions to the scientific field (A, B, C)<br>Scientific Results<br>Did the scientific results contribute to the scientific field in question?<br><br>Non-Proliferation Results<br>Did the scientific work contribute to non-proliferation objectives?<br>Other<br>Did the project lead to additional follow-up projects? | |
| Comments | |
| III. Impact (A, B, C)<br>i.e. what was the impact of the results of the project? Did it lead to applied research, commercialization of new technologies, innovation in existing technologies or patents? | |
| Comments | |
| IV. Dissemination of the results | |
| Number of publication in internationally recognized journals (weighted with the impact factor of the journal) | (A, B, C) |
| Number of publication in national journals | (A, B, C) |
| Presentations at the international conferences (weighted with the “impact factor”: invited, oral, poster) | (A, B, C) |
| Comments | |
| Average score of IV | (A, B, C) |
| V. Collaboration network beween CIS Institutes (A, B, C) | |
| VI. Partnership and collaboration with Foreign Institutes (A, B, C) | |
| Final overall evaluation | (A, A/B, B, B/C, C) |
| Assessment of potential for further development and application | |
| * A = all project objectives met;<br>A/B = most project objectives met;<br>B = all project objectives partially met;<br>B/C = most project objectives partially met and<br>C = project objectives not met. | |

# Annex 4. Summary of Scores of Projects on Radiation Sensors

TOTAL RATINGS: A = all project review criteria met; A/B = most project review criteria met; B = all project review criteria partially met; B/C = most project review criteria partially met and C = project review criteria not met.

| Project N | Project title | Reviewer A | Reviewer B | Reviewer C | Reviewer D | Reviewer E | Reviewer F | Reviewer G | Consensus Score |
|---|---|---|---|---|---|---|---|---|---|
| 822 | Multichannel Clinical Dosimetry | B/C | B | B | B | B/C | B/C | B/C | B/C |
| 1246 | Nondestructive Burnup Measurements | B/C | C | C | B | B/C | B | B/C | B/C |
| 1449 | Safe Transportation of Excess Plutonium | A/B | B | B | B | A/B | B | B | B |
| 1559 | Aerocomplex for Radiation Monitoring | A/B | B | B | B | A/B | A/B | B | B |
| 1639 | Tracking System for «Atlas» | A | A | A | A/B | A/B | A | A/B | A |
| 1644 | Nuclear Materials Identification | B | B/C | B/C | B | A/B | B | B | B |
| 1800 | End-cap ATLAS Tracker | A | A | A | A | A | A | A/B | A |
| 1834 | Portal Detectors for Nuclear Materials | B | A/B | A/B | B | B | B | B/C | B |
| 1933 | Remote Detection of Alpha Pollution | B/C | B/C | B/C | B/C | B | B/C | B/C | B/C |
| 1954 | Fissile Materials Identification Device | B | A/B | A/B | B | B | B/C | B | B |
| 1956 | Database on Silicon Nuclei Fragmentation | A/B | A/B | A/B | A/B | A/B | A/B | B | A/B |
| 1999 | Inner Tracker and Multiplicity Detector for «Alice» Experiment | - | A | A | A | - | - | A/B | A |
| 2134 | Thermal Analysis for ATLAS Detector | B | A/B | - | B/C | B | B | B | B |
| 2283 | Diamond Spectrometers and Dosimeters | B | B | B | B | B | B | A/B | B |
| 2353 | Intelligent Detectors for Emergency and Ecological Monitoring | B | A/B | B | B | B/C | B | B | B |
| 2500 | Calibration of the Space Solar Patrol | A/B | A/B | A/B | B | A/B | A/B | B | A/B |
| 2503 | Gas Sensors and Radiation Detectors for Monitoring | B | B | B | B | A/B | B | B | B |
| 2584 | Reactivity Evaluation Device | B | B/C | - | B/C | B | B | B | B |
| 2637 | Nuclear Materials Detection by Photoneutrons | B | B | B | B | B/C | B | B/C | B |
| 2714 | Detection of Explosives by the Gamma-Activation Method | C | C | B/C | C | B/C | B/C | C | C |
| 2719 | The LHCb Hadron Calorimeter | A/B | A/B | A/B | A/B | A/B | A | B | A/B |
| 2728 | Radiation Detectors on Base of TlBr Crystal | B/C | B | B | B/C | B/C | B | B/C | B/C |
| 2732 | Search for Neutron Source in Urban Areas | B | B | B | B/C | B/C | B/C | B | B |
| 2880 | Start Detector for ALICE Experiment | A/B | A/B | A/B | A/B | A/B | A/B | A/B | A/B |
| 2978 | Digital Technology for Fissile Materials Detection | A/B | B | A/B | B | A | B | A | A/B |
| 3024 | Semiconductor Coordinate-Sensitive Detectors | A/B | A/B | A/B | A/B | B | A/B | A | A/B |
| 3090 | Calorimeter Modules for New Generation Colliders | A/B | A/B | A/B | A/B | B | A/B | A/B | A/B |
| 3534 | Device for Detection of Explosives | B | B | B | B | B/C | B | B/C | B |
| 3785 | Fast Gamma-Ray Spectrometry | A/B | A/B | A | B | A/B | B | B | A/B |
| A-1165 | Scintillators for Positron Emission Tomographs | B | A/B | B | B | - | B | B | B |
| A-1292 | Converters and Detectors for X-Ray Imaging | B/C | C | C | B/C | - | B/C | B/C | B/C |
| G-1160 | Nanocrystalline Scintillators | B/C | B/C | B/C | B | - | B/C | B/C | B/C |
| G-646 | Selective Detectors for Nuclear Radiation | B | B/C | B/C | B | B | B | B | B |
| G-982 | Detectors Based on Cherenkov Effect for NPP Safety | B/C | B/C | B/C | B/C | - | B/C | B/C | B/C |
| T-1157 | Modeling of Gadolinium-Based Neutron Converter | B/C | B/C | B/C | B/C | - | B/C | B/C | B/C |

# Annex 5. Area of Projects and Ranking of Scores

| Project N | Project title | Consensus Score |
|---|---|---|
| Detectors in high energy physics | | |
| 1639 | Tracking System for «Atlas» | A |
| 1800 | End-cap ATLAS Tracker | A |
| 1999 | Inner Tracker and Multiplicity Detector for «Alice» Experiment | A |
| 2500 | Calibration of the Space Solar Patrol | A/B |
| 2719 | The LHCb Hadron Calorimeter | A/B |
| 2880 | Start Detector for ALICE Experiment | A/B |
| 3090 | Calorimeter modules for new generation colliders | A/B |
| 2134 | Thermal Analysis for ATLAS Detector | B |
| New sensors development | | |
| 1956 | Database on Silicon Nuclei Fragmentation | A/B |
| 3024 | Semiconductor Coordinate-Sensitive Detectors | A/B |
| 3785 | Fast Gamma-Ray Spectrometry | A/B |
| 1834 | Portal Detectors for Nuclear Materials | B |
| 2584 | Reactivity Evaluation Device | B |
| A-1165 | Scintillators for positron emission tomographs | B |
| A-1292 | Converters and Detectors for X-Ray Imaging | B/C |
| G-1160 | Nanocrystalline Scintillators | B/C |
| Detectors systems | | |
| 2978 | Digital Technology for Fissile Materials Detection | A/B |
| 1449 | Safe Transportation of Excess Plutonium | B |
| 1559 | Aerocomplex for Radiation Monitoring | B |
| 1644 | Nuclear Materials Identification | B |
| 1954 | Fissile Materials Identification Device | B |
| 2283 | Diamond Spectrometers and Dosimeters | B |
| 2353 | Intelligent Detectors for Emergency and Ecological Monitoring | B |
| 2503 | Gas Sensors and Radiation Detectors for Monitoring | B |
| 2637 | Nuclear Materials Detection by Photoneutrons | B |
| 2732 | Search for Neutron Source in Urban Areas | B |
| 3534 | Device for Detection of Explosives | B |
| G-646 | Selective Detectors for Nuclear Radiation | B |
| 822 | Multichannel Clinical Dosimetry | B/C |
| 1246 | Nondestructive Burnup Measurements | B/C |
| 1933 | Remote Detection of Alpha Pollution | B/C |
| 2728 | Radiation Detectors on Base of TlBr Crystal | B/C |
| G-982 | Detectors Based on Cherenkov Effect for NPP Safety | B/C |
| T-1157 | Modeling of Gadolinium-Based Neutron Converter | B/C |
| 2714 | Detection of Explosives by the Gamma-Activation Method | C |

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