Application of High-Pressure Xenon Detectors in Portal Safeguard Systems and for Monitoring Nuclear Waste

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Abstract

Constellation Technology Corporation has developed a family of high-pressure xenon ionization chambers (HPXe) with working medium masses between 100 g and 2 kg. The detectors demonstrate a good energy resolution (below 3%FWHM at 662 keV for 1 kg detector) that is close to the resolution of room temperature semiconductor detectors with a few grams of working mass. The detectors employ relatively a simple design, robust construction and are available in a variety of pipe-like configurations up to 1.5 m long. The sensitive area of HPXe may cover a few square feet and detect gamma rays with an efficiency close to solid state detectors. Both in experimental modeling and computer simulations it is shown that HPXe has a good potential for detecting kilogram amounts of nuclear materials passing through the vehicle portal of a facility designated to store special nuclear materials. HPXe detectors have been tested at hard radiation conditions typical for an orbital space station. There are positive experiences of using HPXe at 120^{o}C with specially designed preamplifiers. There is no temperature or radiation degradation as well as no charge trapping in xenon itself. The radiation stability of the working medium is practically unlimited. All these features make HPXe detectors ideal candidates for monitoring nuclear waste tanks and other installations with hard radiation conditions.

Paper Justification

1. There is an urgent need for reliable and sensitive nuclear radiation systems suitable for detecting the accidental or intentional transport of special nuclear materials through portals at border crossings, exits from nuclear storage facilities, gates of nuclear power plants, etc. The detectors for these systems must be insensitive to environmental temperature extremes and must be rugged and affordable. They must possess good efficiency and energy resolution but not require frequent servicing and maintenance (such as systematic cryogen replacement). Practically all of the nuclear materials (NM) emit gamma rays which constitute a characteristic signature for that material, can penetrate construction materials, and can be used for detection and identification of NM. To date, two general categories of gamma ray spectrometers are used for these purposes:

- Semiconductor detectors (Germanium is the best of them) which have excellent energy resolution (~0.1% at 1 MeV)

- Scintillation detectors (NaI(Tl) is the most popular) which have the advantages of ambient-temperature operation, relatively low cost for unit of mass, and are available in large crystals for construction of high-effective detection systems.

However, semiconductor detectors are very expensive (up to $1,500/g for 1 cm^3 room-temperature detectors such as CZT) and sensitive to hostile environments while scintillation detectors suffer from poor energy resolution.

2. Since 1943, 176 underground storage tanks have been constructed and filled with highly radioactive chemical waste. The tanks are typically 23 m (75 ft) in diameter with up to 3,790 m^3 (1,000,000 gallons) capacities. The wastes are maintained in highly alkaline conditions at temperatures up to 65^{o}C. Fission and activation products generate gamma-ray dose rates up to 11 Gy/h (1100 R/h) in the tank. *In situ* gamma-spectroscopy is used to measure gamma-ray-emitting radionuclide content and distribution within the tanks. This information is used to aid in tank characterization and is being developed as a process monitor of the effectiveness of waste retrieval.

Currently CdTe and CdZnTe detectors are used for gamma-spectrometry inside the waste tanks at the DOE Hanford Site. US Department of Energy supports development of these detectors for the above purposes. However, CdTe and CdZnTe detectors have considerable charge trapping within detector volume which results in spectral degradation at high gamma-ray energy and high dose rates. The high temperature environment degrades the spectrometric characteristics of these semiconductor detectors. That is why they are cooled by circulating ice water or are used for a very limited time.

3. High-pressure xenon is emerging as an important detection medium for high resolution, room temperature gamma radiation spectrometry. Xenon effectively absorbs gamma rays, is mechanically and chemically stable, has relatively low cost (per unit of mass) in comparison with solid state detectors, and can be workable at extremely harmful conditions such as intense radiation fields, mechanical vibration and shock, and high temperatures and pressures. The

physical properties of xenon allow the development of gamma-ray spectrometers with energy resolutions close to room temperature semiconductor detectors such as CdTe, CdZnTe and HgI_2. There are no principal limitations on the dimensions of Xe detectors, which may be built in a variety of configurations such as cylindrical or tunnel-like with dimensions sufficient to pass loaded trucks through. Xenon is also a relatively low cost material (market price for high-purity xenon is about $1/g).

Constellation Technology Corporation has developed a family of high-pressure xenon ionization chambers (HPXe) with working medium masses between 100 g and 2 kg. The detectors demonstrate good energy resolution (below 3%FWHM at 662 keV for a 1 kg detector) that is close to the resolution of a room temperature semiconductor detector with a working mass of only a few grams. The detectors employ a relatively simple design, a robust construction, and are available in variety pipe-like configurations up to 1.5 m long. The sensitive area of HPXe may cover a few square feet and detect gamma rays with an efficiency close to solid state detectors. Constellation HPXe spectrometers are constructed in portable and mobile systems available for testing in conditions of nuclear storage facilities or plants.

HPXe detectors could find applications in detector systems identification of nuclear weapons and weapon grade materials, portable spectrometers for battlefield use, autonomous nuclear monitoring systems in remote locations and storage facilities, and security portal systems to support nuclear non-proliferation. In experimental modeling and computer simulation, HPXe has shown a good potential for detecting kilogram amounts of nuclear materials passing through the vehicle portal of a facility designated to store special nuclear materials.

HPXe detectors have been tested at hard radiation conditions typical for an orbital space station. There is a positive experience of using HPXe at $120^{o}C$ with a specially designed preamplifier. Instead of a semiconductor transistor, a ceramic vacuum tube has been used in this preamplifier. There is no temperature or radiation degradation as well as no charge trapping in the xenon itself. Radiation stability of the working medium is practically unlimited. All these features make HPXe detectors ideal candidates for monitoring nuclear waste tanks and other nuclear installations with hard radiation conditions.

1.1.1 Biographical sketches

Alexander I Bolozdynya, Ph.D., Chief Physicist

1.1.1.1.1.1 Constellation Technology Corporation

PROFESSIONAL EXPERIENCE

Chief Physicist, Constellation Technology, 5/00 – present

Summary of responsibilities: project management of DOD projects for development of high-pressure xenon electroluminescence detectors, HPXe detectors for portal applications, and high-pressure helium scintillation neutron detectors.

Senior Research Associate, Case Western Reserve University, 2/98 – 5/00

Summary of responsibilities: development of instrumentation for astrophysics experiments in particularly cryogenic germanium detectors to detect weakly interactive massive particles compiling cold dark matter of the Galaxy; member of CDMS collaboration.

Senior Research Associate, Rush-Presbuterian-St.Luke's Medical Center, 2/98 – 5/00

Summary of responsibilities: research and development of a novel X- and gamma ray imaging instrumentation in particularly high sensitive cylindrical Compton camera for nuclear medicine applications.

Principal Research Scientist, Consultant of Nuclear Systems Research, Nuclear Medicine Group of Siemens Medical Systems, Inc., 10/94 – 10/96

Summary of responsibilities: executing of research projects, research and development, modification, improvement and enhancement of γ-imaging detectors for nuclear medicine applications; research and development of high pressure xenon electroluminescent cameras.

Head of Laboratory, Head of group, Senior Scientist, Research Scientist, 9/81-1/95

Summary of responsibilities: general management of experimental physics laboratory; spectroscopy of high energy electromagnetic radiation; R&D for novel nuclear radiation detectors; investigation of electro-optical phenomena in noble gases, liquids, solids and two-phase systems, participation in CDMS collaboration searching for cold dark matter, GEM collaboration for SSC, PHENIX collaboration at RICH, WASA collaboration at CELCIUS.

Raymond P. DeVito, Ph.D., Director of Detector Technology

1.1.1.1.1.2 Constellation Technology Corporation

PROFESSIONAL EXPERIENCE

Director of Detector Technology and Project Manager, Constellation Technology, 9/99 – present

Summary of responsibilities: Project leader for DOD development on high sensitivity radiation detectors, project leader for commercial development of instrumentation utilizing mercuric iodide, project leader for Xenon detector development.

President and Chief Scientist, Mosaic Imaging Technology, 10/97 – 9/99

Summary of responsibilities: Chief Executive Officer; strategic technology leadership; overall direction of the company; working project leader and project participant; external research relationships, staffing and balance sheet.

Director of Research, Research Manager and Group Leader, Siemens Medical Systems, Nuclear Medicine, 5/86 - 10/97
Summary of responsibilities: corporate technology management including identification, evaluation and assimilation of new technology; overall direction of the research department; development of processes for research and innovation; originate, plan and facilitate research group activities and multiple project management; external research relationships, supervision, staffing and total research budget; Chair of the corporate patent committee responsible for patent actions and policy.
Principal Research Scientist, Siemens Gammasonics, 9/83 - 5/86
Summary of responsibilities: technology solutions to business and product issues; produce and develop original new product ideas; transfer of technical information to other groups. Summary of accomplishments: technical leader for clinical evaluation of energy weighted acquisition; technical leader for evaluation of weighting factors for WAM; technical leader for bone densitometer option.
Research Associate, Indiana University Cyclotron Facility, Bloomington, IN, 9/81 - 8/83
Guest Scientist, GSI, Darmstadt, Germany, 1/80 - 8/81

Anatoli A. Arodzero, Ph.D., Principal Physicist
1.1.1.1.1.3 Constellation Technology Corporation

PROFESSIONAL EXPERIENCE
Principal Physicist - Constellation Technology Corporation, 07/01 – present
Summary of responsibilities: Participating in research and development of high-pressure xenon electroluminescence detectors and high-pressure helium scintillation neutron detectors.
President and CTO – Discover Lab Corporation, 09/99 – 06/01
Summary of responsibilities: Manages daily company operations, Developed a novel technique for remotely scanning 3-D body shapes, Developed the World-Wide Student Laboratory Project.
Project Manager, Research Associate – Department of Physics, University of Oregon, 02/91 – 09/99
Summary of responsibilities: Research, design, development, testing, commissioning and operating instruments and set-ups for high energy physics (GEM Detector at the Superconducting Super Collider, SLD Detector at the Stanford Linear Collider, Si/W sampling calorimeter for the Next Linear Collider Project) and for gravitational wave physics (LIGO Project).
Visiting Scientist - California Institute of Technology, 04/97 – 08/98
Summary of responsibilities: Investigated cosmic ray induced radiation effects in active elements of interferometric gravitational wave detectors (LIGO Project). Participated in the operation of the 40-m LIGO laser interferometer.
Staff Scientist – Experimental Physics Division, Institute of Nuclear Physics, Moscow State University, 02/89 – 02/91
Summary of responsibilities: Research and developed large-area silicon detector modules with integrated analog/digital multichannel front-end electronics and fiber optic links for calorimeter of the 3-TeV accelerator complex.