A new vacuum insulated tandem accelerator for detection of explosives and special nuclear materials

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ABSTRACT

This paper describes a radiation source that can be used to actively interrogate containers, trucks, trains, cars, etc to determine the presence and location of chemical explosives and special nuclear materials such as uranium and plutonium. Active interrogation methods using high energy photon or neutron sources to induce fission are the only feasible option for detection of highly enriched uranium (HEU) because passive detection methods are easily compromised by even moderate amounts of shielding. For detection of chemical explosives, the same active interrogation device can be used to produce resonant photons that can detect nitrogen that is used in most chemical explosives.

The accelerator based system described here produces a penetrating beam of high energy photons or neutrons that can "see" inside a sealed container. If chemical explosives or special nuclear materials are present, they will emit a characteristic signal that is detected and interpreted by electronic sensors. Shielded "dirty bombs" can be detected by the attenuation of high energy photons caused by the density of the shield material.

The interrogating source of radiation is based upon a new high current negative ion source and high current tandem accelerator. The accelerator accelerates ions and projects them onto an appropriately designed target. The target converts the energy of the ion beam into a high energy highly penetrating photon or neutron beam. The beam is made to pass through the container. If explosives, special nuclear materials or shielded dirty bombs are present, the beam together with a suitable detection system uniquely identifies the location, amount and density of material.

Keywords: autonomous measurements and monitoring, nuclear resonance, explosives, special nuclear material, tandem accelerator, advanced sensor technologies

1. INTRODUCTION

This paper is concerned with the threats posed by radiological weapons and chemical explosives or the combination of these into so called "dirty bombs". The most potentially catastrophic terrorist threat involving radioactive materials is the possibility of a self-sustained fission chain reaction detonated in an urban area. This scenario is credible and is taken very seriously by the federal authorities. Such an event could result in a significant number of deaths and massive devastation. The resulting fallout, containing highly radioactive fission and activation products, would contaminate many square miles. Such a device need only contain several kilograms to a few tens of kilograms of a fissile isotope. It could be transported in a shipping container or a small truck, and would be difficult to detect because of the relatively small amount of external radiation that it would produce, especially if shielded, before detonation.

The first step in prevention of such a devastating terrorist attack requires that terrorists do not obtain the essential ingredient for building these devices, especially the materials used in an atomic bomb, namely, fissile actinide isotopes such as U-235 or Pu-239. However, if they are obtained, the fissile material must be detected either before introduction into the U.S., or during transport and before assembly into a functional device.

Other credible threat scenarios include the use of ordinary radiological materials as potential weapons. A noninclusive list of potential threats includes the use of so-called “alternate nuclear materials” or the generation of “dirty” bombs,

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which use a combination of conventional explosives and nuclear material. Dirty bombs can be detected by passive radiation monitors if they are not shielded. If they are shielded, active interrogation using $\gamma$-rays is needed to detect the thick shield material required to hide the highly radioactive material.

Another threat is the potential for bulk amounts of chemical explosives including improvised explosive devices (IEDs), which could be explosives left on trains, car and truck bombs and others. They could be used to spread terror in the population or they could be used to produce long lasting threats to commerce by destroying bridges, tunnels and other commercially vital choke points.

Ideally, the first line of defense against these threats is to secure the basic materials so they cannot be obtained and weaponized. The second line of defense is reliable, accurate and rapid detection. The method described here is an active interrogation and detection device. It employs a new type of high current ion accelerator to produce an intense source of energetic penetrating radiation that causes the suspect material to reveal its presence without human interpretation.

The need to detect both traditional and alternate nuclear materials leads to many requirements that are not met by current scientific technologies (e.g., simple, inexpensive, rapid, detection of nuclear material, detection of chemical explosives, detection of “dirty bombs” versus fissionable materials, etc.). Any systems employed for this purpose must address the requirements of rapid throughput, elemental/isotopic discrimination, and low system cost. The system described here employs a new high current tandem accelerator that will deliver a beam current of 10 mA of protons or deuterons at energies up to 2.5 MeV to appropriate targets to produce intense beams of penetrating high energy neutrons or photons. The resultant radiation together with appropriate detectors forms the complete active interrogation and detection system.

The scale of the interrogation system is shown in the artist’s sketch of Figure 1 above. The high current tandem accelerator accelerates a deuteron or proton beam up to 2.5 MeV and ion current up to 10 mA. When the ions impact specific targets, they cause reactions that produce penetrating radiation in the form of neutrons or photons. The penetrating radiation passes through the container and if SNM, chemical explosives or “dirty” bombs are present inside the container, a unique and unambiguous response is generated and detected by an array of photon detectors located outside the container.

1.1. The high current tandem accelerator system

An active interrogation device that will be deployed in seaports, border crossings and tunnels and other choke points must satisfy the requirements of high reliability and high throughput. The system described here is based upon a 1.25 MV tandem accelerator that uses a proven industrial high voltage power supply and a new ion beam acceleration approach designed to overcome previous beam transmission limitations. The reliability issue is addressed by incorporation of a proven industrial power supply and the high throughput is addressed by new developments in implementing the ion source and the novel design of the tandem accelerator.

The 1.25 MV high voltage power supply is a magnetic coupled voltage multiplier circuit with dc voltage output. The power supply is housed in a pressure vessel with SF$_6$ gas insulation. It has a current capability of 40 mA at maximum voltage. More than 70 of these power supplies are in operation in industrial plants in countries throughout the world.
Until now, they have been configured with negative voltage output and used as electron accelerators. They are built by the Budker Institute of Nuclear Physics, the premier Russian accelerator laboratory for dc accelerators. In our project, we have taken this proven power supply and configured to operate with positive output voltage in a tandem acceleration system.

Consider the advantages of the tandem approach to ion acceleration. In an ordinary dc ion accelerator, a positive voltage is developed in the terminal of a high pressure gas insulated high voltage power supply that contains a source of positive ions. Positive ions produced at a low pressure in the ion source are accelerated in vacuum to ground potential due to electrostatic force of repulsion between the positive ions and the positive terminal. In the acceleration process, the ions gain kinetic energy proportional to the charge of the ion times the potential difference they pass through. If \( V \) is the potential of the high voltage terminal, the change of kinetic energy is \( \Delta KE = n \times e \times V \), where \( n \) is the charge state, and \( e \) is the electronic charge.

In a tandem accelerator, a positive dc voltage is developed at the output terminal of the power supply. The voltage is applied to a relatively simple foil or low pressure gas filled cylinder called the charge exchange target. The charge exchange target is designed to strip electrons from a negative ion beam that passes through it. In operation, negative ions produced in an ion source located in the vacuum system outside the accelerator, are formed into a beam and injected into the tandem where they are accelerated toward the charge exchange target. The negative ions pass through the charge exchange target where removal of electrons converts the charge state from negative to positive (and some neutrals). The positive ions that exit the charge exchange target are repulsed by the positive potential of the accelerator and accelerated to ground. The total energy change of the injected negative ions is \( \Delta KE = (1 + n) \times e \times V \), where \( n \) is the charge state of the ions on exit from the charge exchange target. For negative ions that lose two electrons, \( n = 1 \) and the total change of kinetic energy is \( 2 \times e \times V \). This shows that the energy gain is twice the potential of the high voltage power supply.

The advantages of the tandem over “single ended” accelerators are:

- The ion source, which needs fairly frequent servicing when operated at high current, is located outside the pressurized high voltage system, and
- The power supply provides the same energy ion beam at only half the dc voltage.

Although power supply of a tandem accelerator must supply twice the current of the final beam (2 electrons are removed per ion), higher beam current is usually much simpler to provide than higher terminal voltage and so there is a net advantage even though the beam power is the same.

Past efforts to produce high current negative ions, accelerate them in an electrostatic tandem accelerator and transport the ions to a target have suffered serious beam current and beam emittance limitations. The problems stem from:

- Past limitation of negative ion sources to produce low emittance, high output current negative ion beams,
- Destruction of weakly bound negative ions due to collisions with gas in the ion source and in the low energy beam transport system before they are accelerated to high energy,
- Voltage instability due to charge buildup on the insulating structure of the high voltage acceleration tube
- Run away vacuum in the accelerating structure due to loss of stripper gas from the stripper canal and buildup of neutrals due to charge exchange with the ion beam

With the recent advent of very high current negative ion sources, the main limit on hydrogen and deuterium ion beam current from tandem accelerators is the transmission of the beam through the accelerator to the target. The solution to overcoming this limit begins with the negative ion source. The ion source must have high brightness, high stability and long life time. In addition, the accelerating sections of the tandem must be designed to control gas pressure buildup and spark discharges due to charge buildup on insulators in the accelerating column.
1.2. Surface Plasma Negative Ion Source.

The negative ion source is a Surface Plasma Source (SPS) type. The SPS is based on negative ion formation by secondary emission of negative ions enhanced by cesium catalyst admixture to the discharge. The source can operate in pulsed or dc modes. It is designed to optimize average beam current, beam emittance, source lifetime and gas and power efficiency. Increase of average beam intensity up to 10 mA is achieved by an increase of duty factor together with selective cooling of the ion source. Improved discharge configuration and use of insulators with enhanced thermo-conductivity, such as aluminum nitride, are used for this purpose. Both source lifetime and beam intensity are improved by better recycling of cesium with an optimized temperature distribution and by suppression of back accelerated positive ions, which are the main reason of electrode erosion and flake formation.

A schematic of the compact SPS for pulsed and dc high average current operation is shown in Figure 2. The discharge system consists of cathode (4) with a race track discharge gap between cathode and anode (1) but the cathode configuration has only a narrow groove for discharge and good thermal contact with high thermo-conductive insulators (2). The plasma plate (5) has large mass and good thermal contact with the well cooled anode. In pulsed mode, a fast gas valve (14) injects calibrated gas portions into a minimized volume of discharge space. For long time operation, cesium is delivered into the discharge volume by an external cesium delivery system (15). The improved cooling improves cesium recycling on the electrode surface and prevents electrode sputtering and flake formation.

With a small emission aperture, it is possible to have a high enough gas density for complete transformation of fast primary H to cold H by resonant charge exchange cooling. This helps to provide a stable noiseless discharge. These conditions produce a high brightness with a small compromise of emission current density to less than 1 A/cm². The flux of escorted electrons is comparable with the H intensity. With high voltage extraction (i.e. ~ 65 keV) it is good to have a first step of extraction (7) with relatively low voltage (3-5 kV). The magnetic system has special magnetic inserts near the extractor to create concave field lines. This provides for removal of electrons from the extractor gap without trapping them in the gap. The second extractor and third accelerator gap will provide the remaining part of the extractor voltage (up to 60 kV for use in the RFQ injector, or 100kV for BNCT tandem).

Electrode (12) has a positive voltage to suppress penetration of positive ions from the beam to the extractor. This prevents electrodes sputtering by back accelerated positive ions. For further beam transportation, magnetic focusing with partial space charge neutralization, or strong electrostatic focusing will be used.

1.3. The vacuum insulated tandem accelerator

The two most important limitations on beam current transmission in high voltage dc accelerators are related to problems that develop in the acceleration tube. They are: sudden change of voltage gradient caused by spark discharge due to charge buildup on insulators in the acceleration tube and pressure buildup and beam scatter caused by poor vacuum due to limited beam tube pumping. The vacuum insulated tandem accelerator is designed to overcome these difficulties.

In a conventional tandem accelerator there are two accelerating columns with the charge-exchange target in between. The accelerating columns are built of a series of ceramic or glass insulators joined to metal electrodes that together
provide a vacuum enclosure for beam transport and a means to establish the voltage gradient from the high voltage terminal to ground potential. The transport of more than a few milliamperes (mA) through the columns and the charge-exchange target is fundamentally limited by the two mechanisms described above: charge buildup on insulators and high gas pressure in the acceleration tube.

In the vacuum insulated tandem accelerator (VITA), there are no accelerating columns. The charge-exchange target is supported on the top of a voltage graded insulator that is pressurized with SF₆ gas. An array of coaxial cylindrical electrodes of increasing diameter encloses the high voltage terminal and serves to establish a uniform gradient from the high voltage terminal to ground in the radial direction. The array of coaxial cylinders is situated inside a continuously pumped vacuum vessel. The centerline of the ion beam passes through circular openings in the shield electrodes and through the axis of the charge-exchange canal.

The thin walled openings in the electrostatic shields contribute very little to the focusing of the ion beam during acceleration. The largest contributions to ion beam focusing are the physically symmetric openings at the entrance and exit of the grounded vacuum vessel, with the entrance lens being by far the stronger lens due to the lower energy of the injected ion beam. Beam optics simulations of acceleration and transmission and experience using the vacuum insulated accelerator as injector to a proton linac show that proton beams with current up to 40 mA can be accelerated in this geometry. The figures below show the results of beam current simulations for final energy of 2.5 MeV and beam currents from 1 to 40 mA.

1.4. Overall performance of the vacuum insulated tandem accelerator system

The vacuum insulated tandem accelerator system is currently under construction. The ion source has been tested at beam currents up to 15 mA of negative hydrogen ions. The measured beam emittance is 150πmm-mrad for 90% current at 22 keV with a beam current of 8 mA. This transforms to about 15πmm-mrad at 2 MeV. The high voltage power supply provides 40 mA (20 mA of ion beam current to the tandem) at an output voltage of 1.25 MV with 0.1% energy regulation. Various targets are being constructed to produce neutrons and high energy gamma rays. Beam transport simulations have been carried out using the measured values of current and emittance of the actual ion source. Results of beam transport simulations are shown in Figure 4.

How these beams will be used to detect special nuclear material, dirty bombs and chemical explosives is discussed in the following sections.
2. SPECIFIC METHODS OF DETECTION

The VITA addresses three of the major components that threaten homeland security at shipping ports, border crossings, bridges, tunnels, and critical buildings. They are: transport of weapons usable nuclear material (Special Nuclear Material SNM²), chemical explosives and “dirty bombs.” Using appropriate ion species and beam targets, the VITA can detect each of these threats. The VITA produces a directed penetrating beam of high energy (5 MeV) neutrons from a D-n reaction or it can produce a penetrating beam of high energy (7 MeV or higher) photons from the reaction ^19_F(p,αγ)^16_O reaction to detect SNM using the neutrons or photons to induce fission in fissionable materials³. The VITA can be a source of resonant photons for detection of nitrogen based chemical explosives and the high energy photons produced in these reactions together with suitable detectors will detect the presence of shielded “dirty” bombs by x-ray transmission measurements. The specific details how this accelerator can be used to interrogate cargo and detect these threats are discussed in the following sections.

2.1. Detection of SNM

A grapefruit size amount of SNM, i.e. enriched uranium-235 or plutonium, exploding in Manhattan with tens of thousand of tons of explosive force, could kill hundreds of thousands of people immediately, and many thousands more afterward from radiation poisoning and cancer. It would render New York City virtually uninhabitable for years. Active interrogation of SNM using energetic neutrons or photons based on stimulated emission of prompt or delayed neutrons or gamma rays from fission products. With either neutrons or gamma rays, the interrogating radiation source must provide sufficient fluence (number per unit area) and flux (number per unit area per unit time) on the surface of a quantity of SNM buried inside a standard container to elicit a detectable response in detectors located outside in as short as possible time interval. The container can be expected to contain materials that will attempt to shield the SNM from interrogation and to prevent detection of induced emissions.

2.1.1. Fast neutron interrogation

Early work on detection of SNM using neutron induced fission was based upon emission of delayed neutrons by fission products. The delayed neutrons are emitted from a fraction of a second to a few minutes after fission and have lower energies than the fast prompt fission neutrons. Their presence is a very good indication of the presence of SNM.

However, the yield of delayed neutrons is low, approximately 0.008 per fission in ^239_Pu and 0.017 per fission in ^235_U. In addition, since the energy of delayed neutrons is very low (200-500 keV) they are rapidly attenuated in low-Z hydrogenous cargo so that detection of SNM using them is very difficult, especially when examining large containers filled with common low-Z materials.

Recent studies by Norman and Prussin⁴ have shown that when fission is induced in SNM, many of the resulting short lived fission products produce abundant and unique γ-rays when they β-decay with many of the fission products having half-lives in the range of 1 to 60 seconds. Some of these β-decays have very high energies, which lead to the population of highly excited states and copious emission of high energy γ-rays. The high energy γ-rays are unique and distinct from
the natural background radiation. They propose using this signature for detection of SNM. The most important advantages of this method are:

- The delayed high-energy ($E_\gamma > 3$ MeV) fission product $\gamma$-rays have total intensities approximately 10 times greater than those of the delayed neutrons from thermal neutron fission of SNM.
- The high-energy $\gamma$-rays have much greater penetrating power (by a factor of 10 to 100) in thick cargos than is the case for delayed neutrons.
- High-energy $\gamma$-rays are a distinctive signature of SNM. They are generally not present in the normal background.

This SNM signature, which is proposed for fast pulsed neutron interrogation, can also be used when pulsed high energy photons are used as the interrogating source because the interrogating photon pulse will be off when the delayed fission gamma rays are detected. High energy accelerator based neutron sources like the VITA appear more suited for neutron interrogation than do neutrons from low energy accelerators. The higher energy accelerator produces more intense collimated beams than low energy accelerators due to the kinematic effect of center of mass motion. For example, using the D-D reaction at 2.5 MeV deuteron energy, the VITA will produce a forward directed neutron beam with neutron energy of approximately 5.5 MeV. The total neutron yield and fluence at the location of the SNM will depend on the type of target. Even for a D$_2$O ice target, Figure 5 shows the neutron yield is $4 \times 10^8$ n/s/µA. This corresponds to a total yield of $4 \times 10^{12}$ n/s for a 10 mA deuteron beam. Center of mass motion pushes the angular distribution of the emitted neutrons forward so that $\frac{1}{2}$ or $2 \times 10^{12}$ are emitted into a 60° forward directed cone. At a distance of 300 cm from the source, the flux from the ice target is approximately $2 \times 10^7$ n/s/cm$^2$. If the cross section of the SNM measures 10x10 cm$^2$, the total neutron fluence on the SNM is approximately $2 \times 10^9$ n/s. This estimate, which does not take account attenuation in the container, shows that the beam energy and beam current of the VITA produces a time average exposure of $10^9$ n/s, even with an inefficient D$_2$O target. A liquid lithium target would produce 10 times this neutron fluence on the SNM.

2.1.2. Gamma Interrogation of SNM

Another method of detecting SNM and other nuclear materials is to use the 6-7 MeV gamma rays produced in the $^{19}$F(p,$\alpha\gamma$)$^{16}$O reaction. Like the high energy neutrons discussed in the previous section, these high energy gammas will induce neutron and high energy photon emission from photoneutron and photofission processes in nuclear materials. As mentioned above, the photons produced in delayed emission of fission products produce a stronger signal than the delayed neutrons, have a better chance of reaching the detectors located outside the container and their presence would represent a unique and unambiguous indication of the presence of SNM inside the container.
In this detection application, the high energy gammas produced by the $^{19}$F(p,αγ)$^{16}$O have an advantage over Bremsstrahlung sources. This is because only photons with energy greater than 6-7 MeV can induce fission, which requires the electron energy to be 10 MeV or higher. This high electron energy and a suitable target will convert about 12% of the electron beam power to photons, however, the Bremsstrahlung photon energy spectrum is strongly weighted toward low energy so most of the photon radiation is not useful for detecting SNM. In fact, the high radiation around such a high power electron accelerator is a hazard to those working around it. Furthermore, if this full energy spectrum is directed into the cargo container, it could present a severe radiation hazard to stowaways hidden inside.

On the other hand, the photons produced in the $^{19}$F(p,αγ)$^{16}$O reaction are 6.129, 6.917, and 7.116 MeV for the second, third and fourth excited states of $^{16}$O, respectively, and the radiation is very localized coming from a “point” source on the proton target. The cross section for this reaction is shown in Figure 6. The figure shows the cross section peaks at an energy of about 3 MeV. The cross section at 2.5 MeV is about 200 mbarns. This produces a useful photon flux for cargo inspection. In order to distinguish the delayed photons emitted from the SNM from the interrogating photons, the ion source will be operated in pulsed mode when using this method of interrogation. In pulsed mode, the negative ion source is operated with 100 mA peak pulse current at a 10% duty cycle.

2.2. Detection of chemical explosives

A unique and unambiguous method of detecting nitrogen explosives inside a container is the method of gamma resonance fluorescence (GRF) or absorption (GRA). Use of gamma resonance absorption in nitrogen to detect explosives was first described in 1985 by physicists working at the Soreq Nuclear Research Laboratory in Yavne, Israel. The technique they describe is based upon the existence of a narrow (122 eV) energy level in the $^{14}$N nucleus that results in a strong resonance in the reaction $^{14}$N(p,αγ)$^{13}$C at an energy of 9.17 MeV. The cross section for transition from the ground state of $^{14}$N is exceptionally large which makes this a very useful method to detect the presence of nitrogen, a principal ingredient of most explosives. The vacuum insulated tandem accelerator is able to exploit this method to detect explosives because it offers a reliable, cost effective and bright source of 9.17 MeV photons.

Production of photons with this energy and within this energy width can be accomplished by the reaction of protons incident on carbon-13 isotope at incident proton energy of 1.75 MeV. At this particular energy, the proton is resonantly absorbed in the carbon nucleus producing nitrogen-14 in an excited state. The excited nitrogen decays either back to the original $^{13}$C + p (95%) or it gamma decays to the ground state of $^{14}$N, giving off a 9.17 MeV photon. Because of the narrow energy width of the resonance, not all the gamma rays emitted by the target nitrogen nucleus have the energy needed to be absorbed by nitrogen in the explosive. Due to the interaction with the incident proton, photons the photon energy is Doppler shifted to higher values in the forward direction and lower energy in the backward direction. Analysis of the kinematics shows that for proton energy of 1.75 MeV only those photons emitted at the angle of 80.7° ± 1.5° will have the correct energy to be resonantly absorbed by nitrogen in the explosive. This limitation on proton energy and emission angle leads to stringent limits on the energy stability, energy resolution, beam size and beam divergence at the proton target. Only beams produced by dc accelerators can meet all of these requirements.

Consider a collimator made of an absorber material such as steel, lead, tungsten or concrete with a slot cut into it an angle of 81° ± 1.5° with respect to the beam axis and centered at the point where the proton beam strikes the $^{13}$C target (see Figure 7). The target emits 9.17 MeV photons in all directions but only those emitted within ±1.5° at an angle of 81° with respect to the incident proton beam will be resonantly absorbed. A finite beam spot size, beam divergence and energy spread in the beam at the target result in escape of non-resonant photons though the slot in the shield while
resonant photons that are not produced at the expected center point will not escape through the slot. They are absorbed instead in the shield. The ion beam produced by the VITA has energy variation of less than 0.1% at a beam current of 10 mA. The phase space emittance of the ion beam from the SPS ion source has been measured to be 3 cm diameter and 10 mrad divergence at an extraction voltage of 22 keV. This translates to a phase space area of $15\pi$ mm-mrad at 2 MeV energy. This means that for a beam spot size on the target of 1 cm radius the angular divergence of the beam will be approximately 1.5 mrad, which corresponds to ~ 1°. Therefore, this 10 mA beam from the VITA is an excellent source of resonant photons for this application.

Based on the cross section for the $^{13}$C(p,γ) reaction, there are 6 x 10$^{-9}$ resonant gammas per proton. For a 10 mA beam current, there this means there are 3.6 x 10$^{8}$ resonant photons/s emitted into the differential conical section described above. The density of photons incident on a 1 kg quantity of nitrogen at a distance of 3 m from the source can therefore be calculated. The result is about 1.2 x 10$^{3}$ gamma rays per second per cm$^{2}$.

Since a 1 kg quantity of nitrogen has a cross section area of about 100 cm$^{2}$, the total number of gammas incident is ~ 1.2x10$^{6}$/s. Assuming that 100% are resonantly absorbed and 5% are re-emitted into a solid angle of 4π, the number of photons per second that arrive at a 1 m$^{2}$ detector located a distance 3 meters from the explosive is ~ 600/s. With a detector efficiency of 50%, the count rate from a 1 kg sample of chemical explosive will be will be 300 counts/s. A more typical quantity of explosive is something around 20 kg, which would produce a count rate of 3000 counts/s, which is more than adequate count rate to determine the presence of explosive at a distance of 3 meters from the radiation source.

3. CONCLUSION

The vacuum insulated tandem accelerator system is a new and uniquely capable active interrogation system that can operate at a distance to detect and identify the location and amounts of hidden SNM and explosive materials with very high reliability, and without relying on human judgments. The system is compact and automated, and can be positioned on mobile vehicles, as well as at fixed locations. To detect SNM, it generates and directs narrow beams of high energy neutrons and gamma photons at the object being interrogated. It then senses whether or not SNM is present by looking for a unique gamma ray response that only SNM would produce. It can detect whether or not conventional chemical explosives are present, by generating and directing a narrow beam of gamma photons at a precisely controlled energy to produce unique nuclear resonance reactions in nitrogen atoms (nitrogen is a major component in all explosives). Detection of these resonance reactions by an external detector then identifies the location and amount of explosives inside the object being interrogated.

The key to the system is a new type of particle accelerator now being constructed at the Budker Institute in Russia under a cooperative program involving Brookhaven Technology Group (BTG) and the Budker Institute, funded by the US-IPP (Initiatives for Proliferation Prevention) project. The VITA (Vacuum Insulated Tandem Accelerator) provides much higher particle beam currents than existing devices, with exceptional precision and control of the particle energy. Using a deuteron ion beam it can generate a directed beam of high energy neutrons, ~ 5 MeV, for detection of SNM. Using a proton ion beam, it can generate high energy gamma photons for detection of SNM, as well as a narrow beam of precise 9.17 MeV photons for detection of the nitrogen in conventional explosives.

When completed the VITA system will be able to interrogate large objects in a short time, e.g. a minute or two, to see if there are SNM or explosives present, where they are located, and how much is there. The units can be readily mounted on vehicles for use as a mobile interrogation system or they can be transported to a fixed site for temporary or permanent interrogation service. Interrogation could be carried out at foreign or domestic seaports or airports, at permanent or forward DOD bases, train yards, etc.

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Silvestrov who proposed this unique approach for producing a high current, energy stable proton beam to generate a high flux of epithermal neutrons for boron neutron capture therapy.

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