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Cover Page Footnote

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Addressing Underground, Unmanned Threats: A Case Study of GPR Detecting Illegal Objects at Nuclear Facilities and Enhancing Subterranean Physical Protection Systems

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Abstract

In nuclear installations, any unmanned threat is unacceptable. Such threats are a major issue for the nuclear physical protection system (PPS). Although the PPS of a nuclear power plant (NPP) is well prepared to deal with threats above ground level, until now, a special PPS had never been developed for detecting and tackling underground threats. One example of such a threat is a weapon-carrying, unmanned object operated by remote. Using this technology, a terrorist could launch an attack and overcome security barriers. While a normal PPS would not detect the underground activities of a mobile object, a PPS using a ground-penetrating radar (GPR) could. Therefore, adopting GPR technology at nuclear installations would allow us to detect any illegal, unmanned intelligence object accessing an underground path and would strengthen the subterranean PPS.

Keywords: Unmanned intelligence object, GPR technology, underground physical protection system

I. Introduction

According to IAEA recommendations, we should present best practices for considering a nuclear facility's protection system. At nuclear power plants, unauthorized objects are strictly prohibited. However, a normal protection system cannot observe underground activities. In modern technology, a highly modified and remote-operated intelligence object traveling on a subterranean path can carry terrorist weapons. If we do not seize the object at the beginning, when it tries to pass a protection

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boundary, it will eventually reach the nuclear zone. Then, the intelligence object can disrupt operations. The key worry for a nuclear PPS is that when unmanned intelligence objects are moving on the subterranean path carrying weapons, the usual protection method cannot detect it. Thus, the challenge that these subterranean combat tactics pose is a concerning issue for counter-terror technologies **[*1*]**. But using GPR to deal with unmanned underground threats can be effective for subterranean PPS. A GPR can detect the exact location as soon as an object tries to cross the nuclear protection boundary. The military, security personnel, and border patrols use GPR in various configurations to detect unexploded ordinance. GPR technology helps us to protect borders, aid military operations, and many other underground applications **[*2, 3*]**. Therefore, if we could use GPR technology near the protection boundary for detecting illegal access of any unmanned object, and locate it, then that might provide a special defense to the subterranean PPS at any nuclear facility.

II. Unmanned Objects and the Subterranean Threat to NPP

A 2,400 MWe NPP's area is approximately 1,000 acres, or 4 square kilometers **[*4*]**. Therefore, the center becomes 1 kilometer from each edge. A remote-operated, unmanned intelligence object can easily travel this distance through an underground path—threatening an NPP's security.

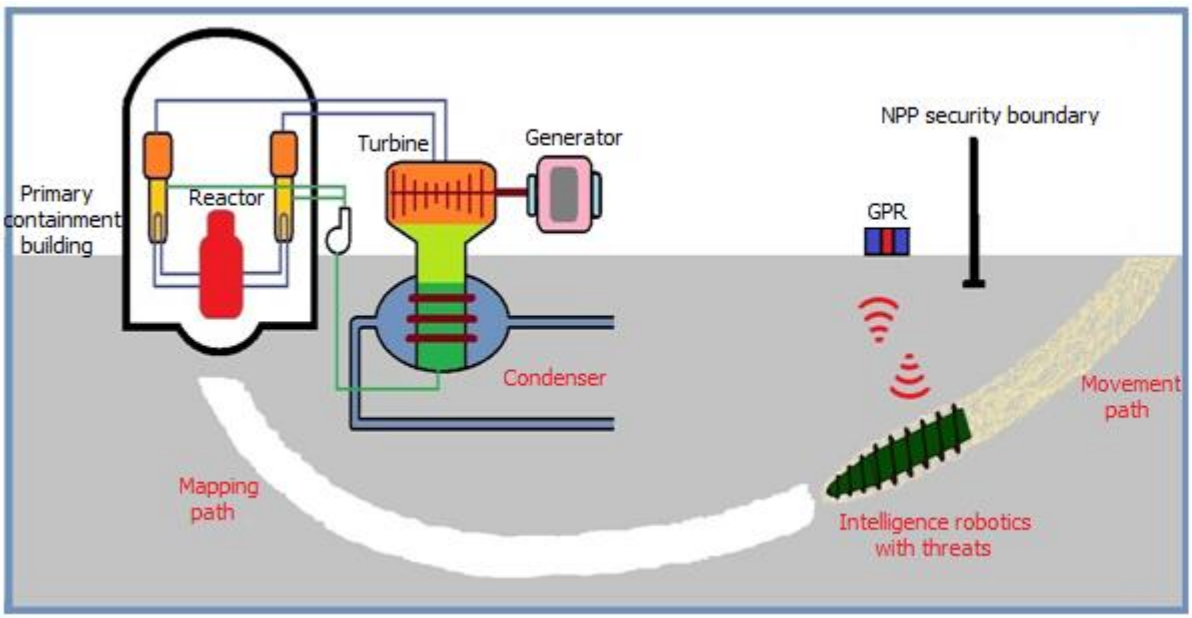

Figure 1. Concept of intelligence robotic threats in a NPP security system

We must consider how to effectively monitor underground activities and ensure a secure PPS at nuclear facilities. Figure 1 shows how an underground, remote-operated object could try to illegally access a nuclear facility. An underground excavation machine, combined with a robotic motion control system, can operate automatically. It has three main components: the excavation system, the control console, and the chamber. The first two parts are used for movement, navigation, the power supply unit, and the control unit, which makes it a remote-operated intelligence device. The chamber is the most significant part of the object because it carries a terrorist weapon. Therefore, that machine can complete the excavation work on its own, without the operator's constant supervision, and is able to cause an accident by reaching the target after a certain period **[*5, 6*]**.

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Figure 2. Automated subterranean moving machine [*7*]

Figure 2 **[*7*]** illustrates an experimental robot developed by students at the Tel Aviv Afeka college. This robot can move underground, in both sand and soft soil, to carry out various missions. China, Canada, Australia, and many other countries have developed unmanned vehicles such as rock drilling jumbos, down-to-hole (DTH), underground mining trucks. These technologies use artificial intelligence, sensors, suitable information techniques, and computers to achieve unmanned mining. These are also operated remotely from the central control room. If terrorists make a long-term plan to attack a nuclear facility, they can find the target by using this kind of unmanned threat. If external power sources are connected by wires, it is easier to reach the nuclear zone by digging a little bit every day as part of a long-term plan. Considering soil quality and power supply availability, one may conclude 50 days is enough time to pass 1 km **[*8*]**.

III. Basic Principles of a GPR System [*9*, *10*]

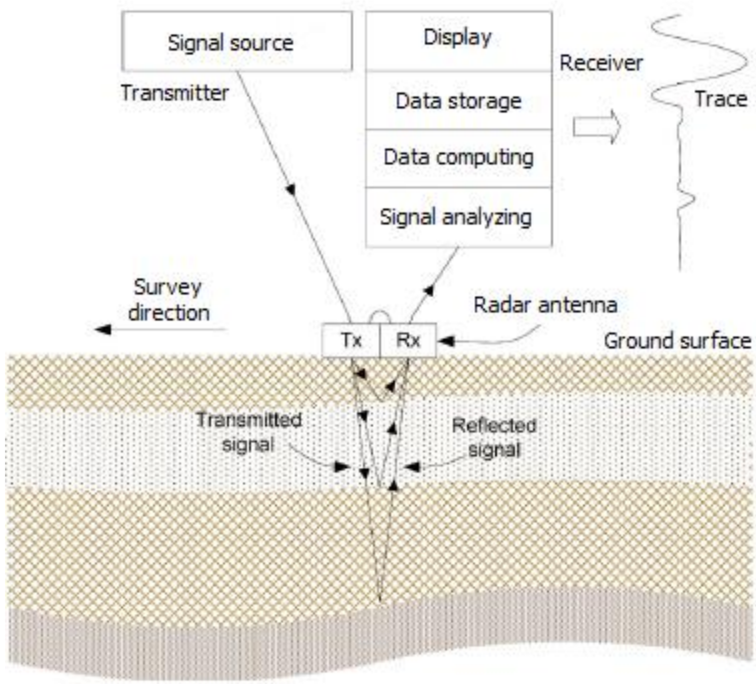

Figure 3. GPR system components and GPR work process [*11*, *12*]

GPR is a nondestructive geophysical method that produces a continuous cross-sectional profile and analyzes stratigraphic sequences of subsurface features without drilling, probing, or digging. GPR's foundation lies in electromagnetic (EM) theory. The GPR system transmits a series of short pulses over a single area, scanning with high frequency (10-1000 MHz) EM energy from an antenna into the subsurface. Its velocity is altered due to several properties of the materials. Whenever the energy encounters a buried object with different permittivity, then the abrupt changes in dielectric constant results in some of the energy being reflected. A receiving antenna then detects the reflected EM energy and records the variations of return signals on digital media. The computer measures the two-way time (TWT), which indicates its depth and location for estimating a two or three-dimensional subsurface profile, which provides horizontal survey distance against depth. Metals are considered a complete reflector and do not allow any signal to pass through it. The propagation of EM energy is controlled by several material properties, like conductivity (σ), permeability (μ), and dielectric permittivity (ε).

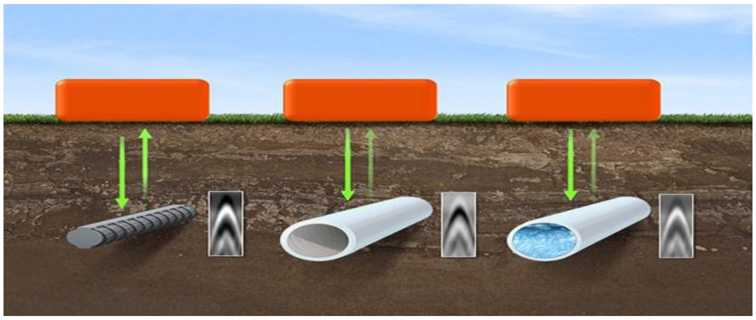

Figure 4. GPR image from subsurface layer [*5*]

Table 1. Variation of GPR Frequency with Depth Ranges

Appropriate application	Antenna choice	Depth range
Concrete, Shallow soils, Archaeology	900 MHz	0-1.0 m
Shallow Geology, Utilities, Archaeology	400 MHz	0-3.0 m
Geology, Environmental, Utility	200 MHz	0-9.0 m
Geologic Profiling	100 MHz	0-30 m
Geologic Profiling	MLF (80,40 32, 20)	0-50 m

Dielectric permittivity strongly depends on a material's water content, which is the primary factor controlling the signal velocity. An increase in either subsurface conductivity or radar frequency will further reduce the radar signal **[*8–10*]**. Therefore, antenna frequency and soil conductivity affect the object's measurement depth.

IV. Underground Threat Detection Process by a GPR System

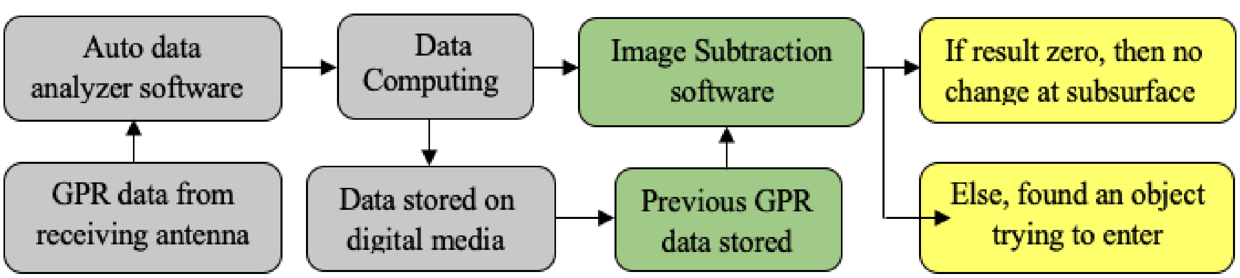

Figure 5. Automated GPR data process and detection system [*13*]

The system is divided into four areas: GPR data acquisition hardware, communication, auto analyzer, and computing. The collection of GPR data is based on high-level commands sent from the work station to

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the auto analyzer. Here, they are translated into low-level commands, digitized by the computing equipment, and stored on a hard disk. An experienced operator then interprets that large amount of acquired data. When an unmanned, underground intelligence object tries to cross the GPR protection line, the GPR signal detects the object within a nanosecond, and signal data is sent to the control room. Then the signal is converted into an image. Image subtraction is a more distinct process to identify an object, as illustrated below:

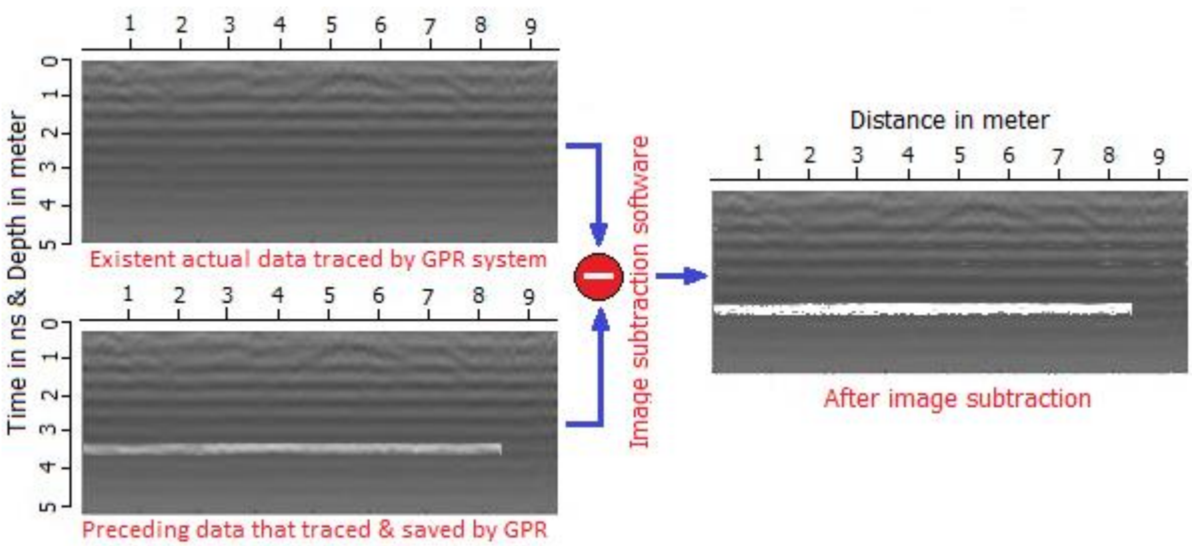

Figure 6. Finding dissimilarities with image comparison software for detecting exotic objects

There are so many ways to compare images programmatically **[*14*]**. Python code for background subtraction using OpenCV is a common and widely used technique for generating a foreground image. It has several uses for object segmentation, security enhancement, and pedestrian tracking. In Figure 6, existent actual data is subtracted from its preceding data saved in the GPR storage system, and then an image subtractor tries to find the dissimilarities between them. That is the main concept for detecting the underground threats by using the GPR system when an unmanned object violates the protection boundary through an underground path.

V. NPP's Subsurface Security with a GPR System

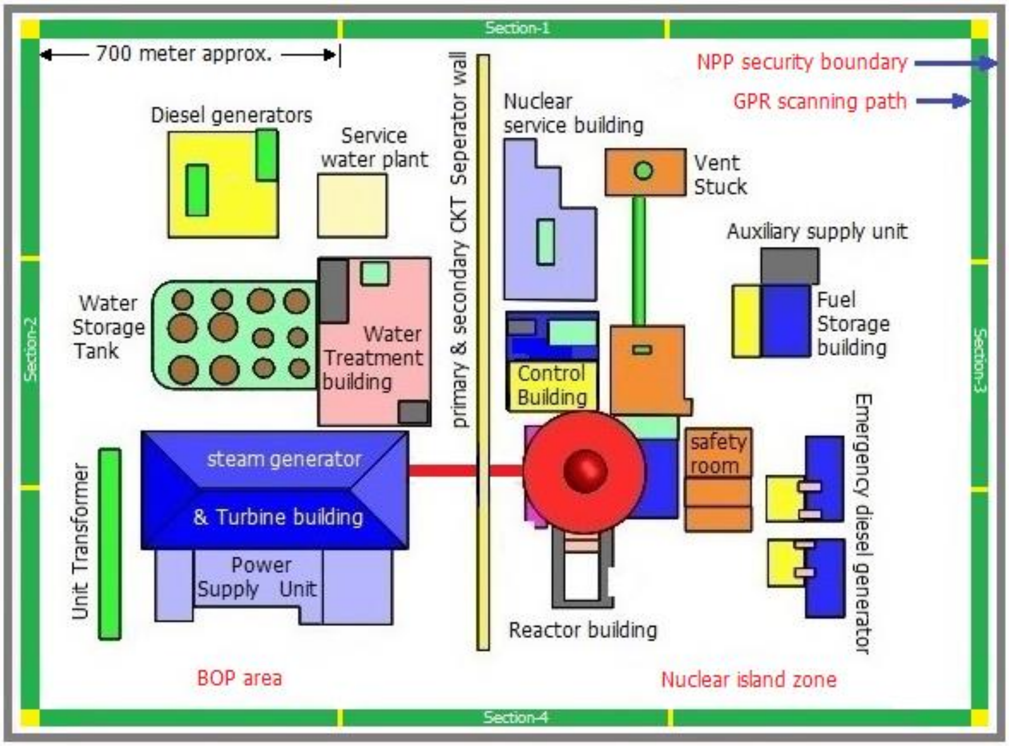

Figure 7. Top view of a typical NPP with surrounding enclosed by security boundary [*15*]

As previously mentioned, a 2,400 MWe NPP area averages 4 square kilometers and has an 8,000-meter-long enclosure. Figure 7 shows a top view of a typical NPP, where we draw a GPR scan path adjacent with its physical protection boundary. GPR can scan continuously along this path. To improve the efficacy of subterranean PPS, the long periphery is divided into four sections, each with three subsections. The subsections are approximately 700 meters long, and it is easy to continuously monitor this distance within very short intervals. A GPR can scan up to 30 km per hour **[*3*]**.

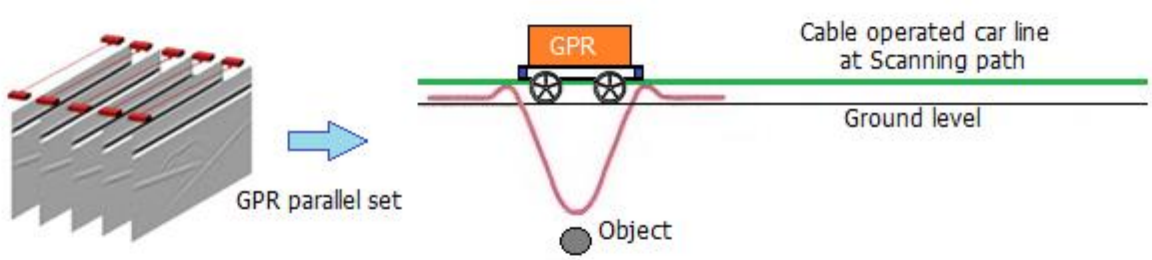

Figure 8. Parallel GPR set on cable car for wide range monitoring in a sub-section

In Figure 8, a parallelly connected 5-piece GPR, called a GPR set, provides wide range 3-D monitoring and continuous scanning of the underground profile. It could travel on the GPR scanning path with the help of an automatic cable car. After completing one cycle for each sub-section, GPR data is sent to the control room. After that, Radar Data Analyzer software analyzes the GPR data and processes the signal into images. Finally, images are sent to an image subtraction software where they are compared and subtracted. Usually, there is no significantly change at the underground profile and image subtraction software would display a similar result. GPR would continue to capture images as per routine work. In one case, when an external object tries to cross the security boundary, GPR captures it and sends to subtraction software to subtract from preceding images. As a result, the additional object is identified at the display of the subtractor. When the object is identified at the end of the subtraction result, we can detect its exact location, depth, and size from the recent data. That can help us avoid unacceptable situations by taking proper actions at the right time.

VI. Cost Effectiveness of a GPR System at an NPP

The cost of a geological profile analysis by a GPR system depends on how many radars we want to use at the whole fence of the NPP's boundary. Here, we consider 4 sections, each having 3 subsections. So, a total of 12 subsections contains 12 GPR sets, and each set has 5 GPRs. Finally, a total of 60 GPR systems is used at the whole enclosure. According to USRADAR INC. **[*16*]**, each GPR costs approximately \$15,000 USD. The total GPR cost (\$15,000 USD × 60) is \$0.9 million USD, and after adding some other associate accessories, the entire system requires \$1 million USD. Recently, installing a two-unit (1200 MWe×2) VVER generation 3^+ reactor costs \$12.65 billion USD **[*4*]**, and if we compare the NPP's total installation cost with the cost of GPR technology, which is only 0.008%, the GPR cost is comparatively low—a reasonable cause to consider using it for subterranean PPS.

VII. Conclusion

Due to a fourth industrial revolution, intelligence objects are developing rapidly, leading to a new era of human civilization. Therefore, we may face new tactics of terrorist threats in the near future. Hence, we need a new version of PPS, one that is prepared to identify any unmanned, underground illegal objects. By using GPR technology, we can easily overcome any type of subterranean threat. It is a testing method used for geophysical survey, archaeological investigation, and detection of buried objects that can scan very quickly. In addition, a GPR system is less costly compared to NPP's total budget, flexible in operation, and is both more accurate and more reliable. It is comparatively easier for terrorists to use small, unmanned, underground intelligence objects as opposed to making large tunnels. Additionally, GPR technology is efficient in detecting any kind of unmanned buried objects. Therefore, we defend against any unauthorized unmanned object by using GPR for underground PPS at the NPP site, which also plays a significant role in enhancing its subterranean physical protection.

VIII. Recommendations

- After identifying unauthorized unmanned objects underground by a GPR system, we need to take action to deactivate it as soon as possible. There are different opportunities for future investigation in this regard.

- Geo phone and vibration sensors are also capable of identifying underground objects when a secret object comes to their nearby area. In the future, we can use these two devices for subterranean protection by installing them in an underground bore-hole at the security fencing.

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