Design of Real-Time Tracking System for Radioactive Material Transportation

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Abstract— The main challenges of radioactive materials transportation are safety and security, so it is important to design a robust and efficient real-time tracking system to monitor the movement and ensure the security of radioactive materials during transportation. This paper presents a proposed tracking sys-tem design, considerations, and key components of real-time tracking for radioactive material during transportation. Three advanced Global Positioning System (GPS) /General Packet Radio Service (GPRS) Hardware modules have been tested for real-time tracking and implemented: SIM-800L, SIM 808, and A9G Module. The system used encrypted communication protocols to achieve accurate and secure tracking. The GPS receiver obtains data concerning the vehicle's position solely in terms of longitude and latitude, disregarding altitude as it is irrelevant to our tracking method, as determined by the satellite, together with the radiation measurements of the radioactive material collected by the radiation sensor. All information is thereafter transmitted via a GSM device to ThingSpeak. GPS and GSM devices interface with an Arduino Nano microcontroller. The geographical location and coordinates are subsequently presented on the map utilizing an HTML-based platform within the OpenStreetMap tool. The results show that the proposed real-time tracking system can enhance the security and safety of the radioactive materials transportation process.

Manuscript received [17 January 2025]; revised [22 June 2025]; accepted [25 June 2025]. Date of publication [21 July 2025].

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Keywords— GPS, GSM, Real-Time Tracking System, Radioactive Material Transportation.

I. INTRODUCTION

There are thousands of radioactive sealed sources that are used in medical and industrial applications. Every year, hundreds of these sources are transported from location to another. During transportation, these sources became out of control due to vehicular accidents or human mistakes, or it may be lost (or stolen). In such cases, the challenge is recovering these sources before causing harm to the public or the environment. The secure vehicle-tracking module is installed in the car to stop thefts by using real-time GPS monitoring. If the car goes off its planned route, an alert is sent out so that the police can respond quickly. Remote engine immobilization is another option. This lets you halt the car from a distance if you think it has been stolen, which stops the thief from getting away.

Regulatory frameworks have long ensured the safe transport of radioactive materials, but advanced tracking systems now enhance security by enabling real-time monitoring, tamper detection, and rapid response to threats. In the last years, there are many efforts and steps have been taken to provide radioactive material transportation security. At the same time these steps have included ensuring the security doesn't conflict with the safety requirements. Globally, there are several significant efforts that have been achieved in implementing a suitable secure method for radioactive material transport. International Atomic Energy Agency (IAEA) provides a guide for recommendation the security methods that can be suitable for adoption by every country according to their regulatory and by the international transport organizations [1, 2].

The IAEA-regulated Convention on the Physical Protection of Nuclear Material (CPPNM) sets the global security standard for transporting radioactive and nuclear materials [3]. Real time tracking is one of the important methods and prerequisites for emphasizing safety, security, and safeguards of the radioactive materials. Argonne National Laboratory (ARG) developed a transport system with a real-time tracking system of radioactive materials during transportation [4]. Such module can track vehicle location and monitoring seal integrity, temperature shock, humidity, and radiation of nuclear and radioactive materials, involving GPS, radio frequency identification (RFID), two-way satellite communication, secured database and web servers, and a pilot RFID command center at Argonne

National Laboratory.

Advanced manufacturing technologies to improve radioactive transportation safety, effective-ness, and dependability were presented in [5]. They proved the possibility, advantages and difficulties of incorporating sophisticated manufacturing into the transportation of radioactive materials. A summary of low-energy nuclear physics charged-particle tracking detectors was provided by [6]. A blockchain technology for tracking nuclear material, a plan for enabling this technology, and enhancing the security and effectiveness of nuclear material tracking is discusses in [7]. Additionally, in [8], the implementation of blockchain and IoT in nuclear waste transportation. A reliable cloud-based framework for radioactive materials tracking was presented in [8]. Cloud based tracking offers front-line and management more consistency and convenience of use and was perfect for quick, asynchronous utilization around a health system [9]. In [10] a design of a portable, inexpensive gamma monitoring system using a CsI(Tl) coupled PIN-type photodiode and specially developed circuits, they evaluated the system for gamma-ray detection properties. An intelligent self-security radioactive material module, combined of in and out vehicle monitoring, the security system focused on four-layered security, and it can detect any illegal attack of the vehicle or the radioactive material movement was provided in [11]. A feasible approach for the detection of illegal radioactive material movement based on space triangle is presented in [12], this method utilizes wireless signal strength which is first filtered and converted to distance data. Wireless communication may suffer from several attacks and need more security algorithms [13, 14] such as WIMAX [15, 16] or WBANs [17].

In Japan, a radioactive material tracking system developed to enable the communication capabilities of sharing some specific information between the relevant organizations and the transporter in case of accident [18]. They used two lines for communication; the cellular phone network and the low orbit satellite network. The transmitted data is encrypted to enforce its security. The security of radioactive source transportation can be achieved by using a continuous monitoring system, which mainly depends on RFID reader and tags illustrated in [19]. The location obtained from the GPS is sent to the control unit through GPRS network. The results show that the tracking system can be used effectively for providing safety and security of radioactive sources in transport.

This paper introduces the board module which consists of the GPS receiver, global system for mobile communication GSM modem. In GPS tracking system, the vehicle location can be sent to remote places by GSM modem. The GPS and GSM module are not discrete components, but they are closely integrated with a microcontroller. Such integration enables a highly customizable design. Consequently microcontroller-based design is often considered cost effective [20, 21].

The coordinates obtained from the GPS receiver are sent to the webserver via GPRS network. Once the users request vehicle monitoring, the request sent from the application to the webserver, that will process this request and responds back to the application, then the received vehicle’s location will be plotted on a map. The main advantage of this module is the progress board that will diminish the size of whole module, and the power loss reduction during the connection of GPS and GSM module with Android. Besides that, it will increase the permanency of the complete module. The utilization of GPS/GSM based method is still very much required in the market. This is because the commercially accessible anti-theft vehicular tracking schemes are very costly. So, there is essential to build an efficient vehicular tracking scheme that is cost operational, user friendly and can secure theft of a vehicle by tracking the location of a vehicle at remote places.

II. Proposed Radioactive Material Tracking System

Figure (1) shows the block diagram of the radioactive material tracking system during transportation. This system consists of a GPS receiver, microcontroller unit, GSM/GPRS module, radiation sensor, and battery-based power supply system. The operation cycle of the system starts by reading the location of the vehicle through the GPS receiver module that connected firstly to at least 3 satellites. The embedded system interprets the output data of the GPS module to extract both the latitude and the longitude of the vehicle. The value of the radiation value is also measured using a semiconductor-based radiation source. The obtained information is then prepared to be ready for sending through a GSM/GPRS module to either mobile phone or to data cloud (Server). Finally, a web application and/or mobile application can communicate with the cloud either in real time or offline.

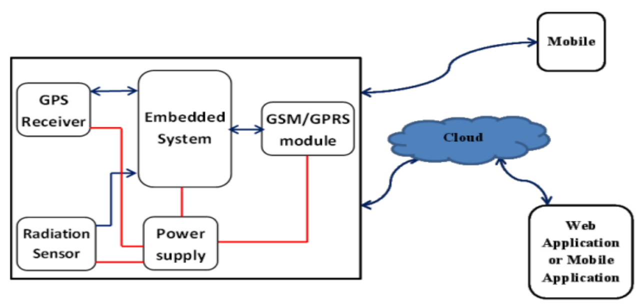


Fig. 1. Block diagram of radioactive material tracking system during transportation.

III. Tracking System Implementation

A variety of GSM and GPS modules are tested with the implemented tracking system to be able to study the different properties of each module to have knowledge about their advantages and disadvantages. The first trial of the tracking system was built using a GSM shield and an Arduino-Uno (for its quick prototyping and to validate the initial concept) to send an SMS message to a mobile. The vehicle location is communicated through a link embedded within SMS message simply consists of the link that contains. After proving the concept using the first trial, Variety of tracking systems were implemented and are introduced in the following sections. The implemented tracking systems use an Arduino-Nano board, 18650 battery shield modules, and a semiconductor-based radiation sensor. The system is designed to send the collected data to the channel of the existing things peak cloud platform.

The principle of utilized hardware in this paper will be given with some details in the following sub sections.

Table I is an example of a adding tables and writing the table title in the paper.

A. Arduino Nano Module

The Arduino Nano shown in Fig. 2 is among the most popular and cost-effective digital control devices globally. The Arduino Nano is a microcontroller device featuring 16 digital pins for many applications. It is applicable for a wide range of tasks, from trivial to huge industrial-scale applications. It can also serve for prototyping and building novel apps. The Arduino Nano is a small, full board that can be used with a breadboard. It is based on the ATmega328. It works pretty like Arduino, but it is in different case. The only thing it doesn't have is a power jack, and it can work with a Mini-B USB cable.

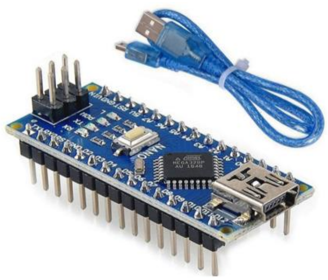


Fig. 2. Arduino Nano board [22]

B. GSM/GPRS Module

In this work, three modules are used and is chosen which better, SIM-800L, SIM 808, and A9G Module. SIM-800L is used during the implementation of the first tracking module. SIM-800L is a Quad-Band GSM/GPRS module that works on frequency GSM 850 MHZ, EGSM 900 MHZ, DCS 1800 MHZ and PCS 1900 MHZ. It can meet the space requirements in the user applications and provide the interfaces between the customer boards and the module. SIM 800L is power saving, this means that the consumption of the current is lower than 0.7 mA in a sleep mode.SIM-800L module does not have its own GPS receiver, accordingly a separate GPS receiver module of type NEO-6M-0-001 is used for determining the latitude and the longitude. The GPS of this type is characterized with accuracy of 2.5 m and require time of 27 s to fix with the satellites in case of cold start (When the GPS module has no prior knowledge of its location, time, or satellite positions (ephemeris data)), and 1 s for hot start situation (When the GPS module has recent ephemeris data, approximate location, and time stored in memory). Both the SIM-800L module and the GPS NEO-6M-0-001 receiver are interfaced separately with the Arduino Nano board through two pins. Fig. 3 illustrates the implemented tracking system based on SIM-800L GSM/GPRS module, NEO-6M-0-001 GPS module, semiconductor radiation sensor, and a battery-based power supply.

The second module is SIM 808 which is a GSM/GPRS+GPS Module shown in Fig. 4. SIM808 is Quad-Band GSM/GPRS module that integrates GPS for satellite navigation. The small solution that integrates GPRS and GPS in an SMT package would substantially reduce both time and costs for clients developing GPS-enabled applications. Equipped with an industry-standard interface and GPS functionality, it enables the smooth tracking of diverse assets at any location and at any time, provided there is signal coverage.

The GPS of this SIM type module is characterized with accuracy of 2.5 m and require time of 32 s to fix with the satellites in case of cold start and lower than 1 s for hot start situation. The SIM 808 module is interfaced with the Arduino-Nano board using 2 pins

(a) SIM-800L module.

(b) Tracking System based on SIM-800L Module

Fig. 3. Implemented tracking system based on SIM 800L GSM/GPRS module

Fig. 4. Tracking System based on SIM-808 Module.

The third module is A9G module, a complete quad-band GSM/GPRS module that integrates GPRS and GPS/BDS within a compact SMD package, thereby conserving time and resources for customers in the development of GNSS applications. The A9G, is suitable for a diverse array of Internet of Things (IoT) applications, particularly in home and industrial control and most of IoT applications. The A9G SMD package facilitates the swift creation of goods using standard SMT equipment, particularly benefiting automation, large-scale, and cost-effective modern manufacturing techniques for many Internets of Things hardware terminal applications. The A9G type module's GPS exhibits an accuracy of 2.5 meters, compared to other modules, and necessitates less than 27 seconds for satellite acquisition during a cold start and under 1 second for a hot start. The A9G module is interfaced with the Arduino-Nano board using 2 pins. Fig. 5 illustrates the implemented tracking system that uses the different Modules, semiconductor radiation sensor, and a battery-based power supply. The interfacing between the Arduino Nano board with the A9G module requires 4 pins to communicate with both the GSM and GPS of the A9G module. The tracking system that uses A9G module achieves fast communication with the satellite system due to its extremely rapid hot and recapture start times, which means it can almost instantly regain a position fix if it loses signal briefly or is restarted. It also has good cold start performance, so it can acquire an initial fix in under half a minute even without prior data. Moreover, it has high GPS/BDS sensitivity: This allows it to quickly acquire and track weak satellite signals, contributing to overall faster and more reliable positioning.

Fig. 5: Tracking System based on A9G Module

More comparative details for these modules are found in table 1 [23].

TABLE I
COMPARATIVE FEATURES OF SIM-800L, SIM 808, AND A9G MODULES

Feature	SIM800L	SIM808	A9G
Connectivity	GSM/GPRS (2G)	GSM/GPRS (2G)	GSM/GPRS (2G)
Data Speed	~40-60 kbps (GPRS)	~40-60 kbps (GPRS)	~40-60 kbps (GPRS)
Power Consumption	~1A (Peak during TX)	~1A (Peak during TX)	~500mA (Peak, lower in sleep)
Typical Uses	SMS alerts, basic IoT	Fleet tracking, basic GPS	Advanced tracking (GPS + cellular)
Cost	Low	Medium	Medium

C. Radiation Sensor

One RD3024 semiconductor radiation sensor shown in Fig. 6. is used as a radiation detector in this work. It operates using a configuration of specialized PIN diodes. Integrated pulse-discriminator, with a temperature-compensated threshold, delivers a genuine TTL signal output. The RD3024 can detect beta, gamma and X-rays.

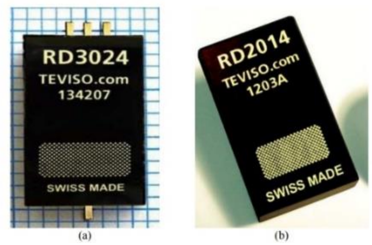


Fig. 6: Semiconductor radiation sensor [24]

D. OpenStreetMap

OpenStreetMap is a free map of the world can be editable by the users. It began in the United Kingdom because of discontent with the scarcity of high-quality, free map data. OpenStreetMap contains information about roads, buildings, addresses and companies, areas of interest, railways, public transportation, land use, and natural features, among other topics. The map is generated and maintained by approximately 5 million registered users and over 1 million map contributors from all over the world, who use free tools and software. OpenStreetMap is used in this work to put the location of the vehicle on the map.

E. ThingSpeak

ThingSpeak is an IoT platform that can enable the collection, visualization, analysis, and responsive action based on real-time data. It is an open-source application initially released in 2010 by ioBridge. It facilitates the construction of IoT systems without the necessity of establishing additional servers. Data gathering is conducted via REST API or Message Queuing Telemetry Transport (MQTT). ThingSpeak website indicates that the API functions as seen in Fig.7. Essentially, things refer to objects equipped with sensors for data collection. Data is transmitted and received by basic (HTTP) POST requests, analogous to visiting a web page and completing a form. This communication occurs via plain text, JSON, or XML. The data is subsequently uploaded to the cloud, where it can be utilized for various reasons. Consequently, data (including commands or selected options) can be collected and transmitted to the cloud, which subsequently relays these messages to the object.

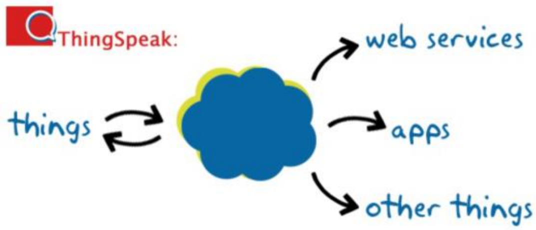


Fig. 7: ThinkSpeak representing itself as 'cloud' interface

IV. Results and Discussion

This section presents the results and discussion of the design of a real-time tracking system for radioactive material transportation. The development of the tracking system can be integrated directly into the vehicle enabling real-time monitoring of its route and whereabouts. Throughout the tracking procedure, the GPS receiver acquires data regarding the vehicle's position in terms of longitude and latitude, as determined by the satellite, together with the radiation measurements of the isotopic material obtained from the RD3024 radiation sensor. All information is thereafter transmitted via a GSM device to ThingSpeak. GPS and GSM devices interface with an Arduino Nano microcontroller. The geographical location and coordinates are subsequently presented on the map utilizing an HTML-based platform within the OpenStreetMap tool.

Due to the vehicle's location coordinates being updated every 5 seconds, ThingSpeak facilitates the creation of a database that may be accessed at any time subsequently. The browser's JavaScript facilitates the presentation of information via straightforward charts to illustrate trends on the webpage, while also incorporating these trends into maps for the user. To establish an effective tracking system for the vehicle, it was necessary to find an appropriate programming language that would be compatible with all three devices: Arduino Nano, GSM device, and GPS device. Consequently, the C programming language has been employed to program the microcontroller utilizing Arduino IDE software. The program facilitated the successful transport of data to and from the satellite. This facilitated a dependable transfer of data into the database through Arduino Nano. Figure 8 shows the block diagram which describes in detail the steps which are implemented by Arduino nano with different sensors and the communication between the tracking device and ThingSpeak webserver.

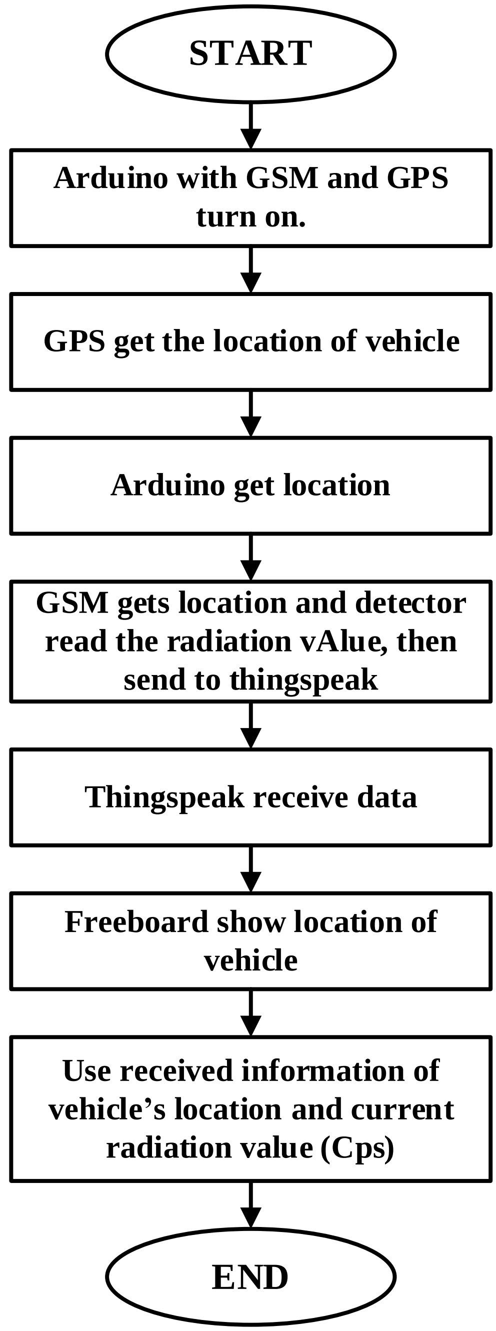
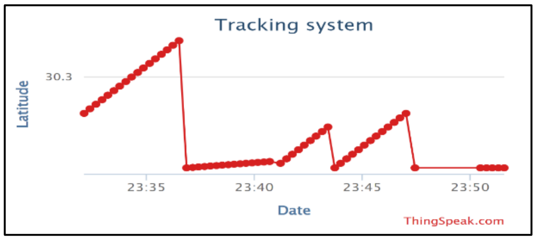


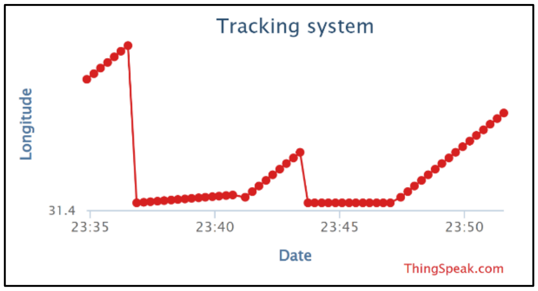
Fig. 8: Block diagram of real-time tracking system

Several tests have been conducted to test the system's ability to adapt by adjusting to changes in the vehicle's location and updating ThingSpeak with the updated latitude and longitude of the new location.

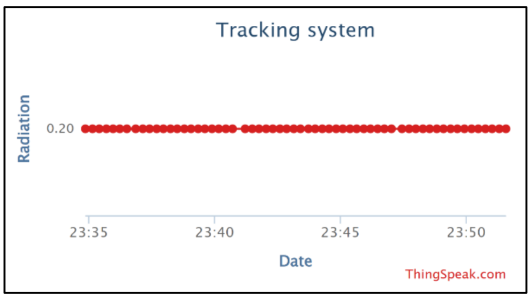
Fig. 9 shows the fields which are sent to ThingSpeak from Arduino nano via GSM module, the first field describes the latitude value, while the second one shows the longitude value of the vehicle location. Field 3 describes the radiation reading of the isotope material in the vehicle. Fig. 10 shows the vehicle location on the HTML webpage which is programmed to show the vehicle path on OpenStreetMap maps.



(a)



(b)



(c)

Fig. 9: (a) Latitude, (b) Longitude, and (c) Radiation Data Displayed on ThingSpeak.

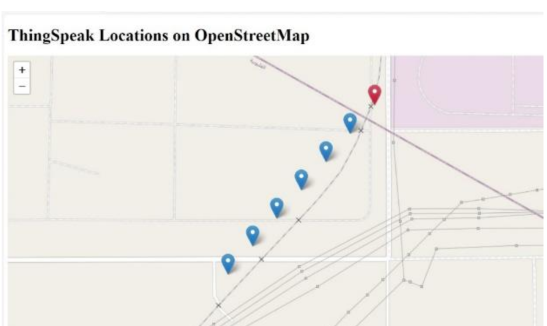


Fig. 10: Vehicle tracking path on OpenStreetMap tool

A. Real Time Anomaly Detection

Real time anomaly detection methodology can have a main and objective role in identifying and mitigating potential threats and radiation leaks during the transportation of nuclear or other radioactive materials. There are some challenges that should be considered in actual design and implementing anomaly detection model for real tracking of contamination during transportation of that material like; external environmental factors as temperature and humidity that can impact the system's readings, system accuracy and sensitivity to detect actual anomalies and avoid false readings. Machine learning and AI algorithms can be utilized efficiently to detect the deviation from normal pattern. The AI based anomaly detection model using isolation forests is used as a real tracking of contamination during transportation of nuclear material or other radioactive material, which in real time as shown in figure 11, it can detect any deviation from normal pattern of contamination which can help in taking a suitable action towards identifying and mitigating potential threats or accidents during transportation.

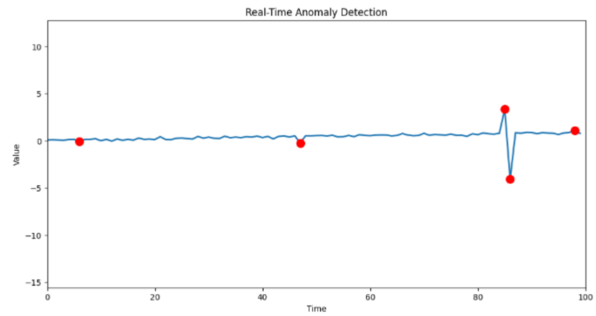


Fig. 11: Real Time Anomaly Detection

B. Security Measures

Safety and security measures have in common the same object of protecting human life, health, and the environment [2]. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security. For ensuring the security of the designed radioactive material tracking systems during transportation, the security measures based on technological advancements, and emerging security risks, should be updated with best practices and regulation. So, we let the monitoring server itself monitor and discover any suspicious data writing or reading trials through deep learning real time detection approach. Safety and security measures must be meticulously to ensure that neither compromise the other.

1. Using computers with fixed IP as a server, and this IP is known only for the working group
2. Each tracking node has certain ID and the data gets encrypted before transmitted to the server
3. Additional random dummy data get added to the tracking information before encryption.
4. Encryption keys could be dynamic random, and the server will discover the decryption keys from the data sent.
5. The server doesn't accept the data unless from known IDs, and with certain password or writing key.
6. The data sent using secure http method (i.e. https), or MQTT secure protocol.
7. There is a reading key or password for reading data from the server.
8. The physical signal already secured by the GSM network provider.

9. There is some kind of hardware security on the tracking Node to make it difficult to extract the code and hardware configuration
10. The server monitors itself & discovers any suspicious data writing or reading trials through deep learning real time detection approach.

V. Conclusion

This paper presented an implementation of secure effective real-time tracking system for radioactive materials during transportation to guarantee the security, safety, and regulatory compliance of such important shipments. Stakeholders can accomplish precise and secure tracking of the transport vehicle and the radioactive material during the transportation process by integrating the advanced technologies such as GPS, geofencing, and encrypted communication protocols. Overall, the security, safety, and effectiveness of the entire transportation process are improved by the development the effective real-time tracking system, where it reduces the risks and guarantees compliance with regulations by giving stakeholders more visibility, control, and response capabilities. By implementing this tracking system, Stakeholders can have confidence about the safe transportation of radioactive materials if such a framework is put in place.

Acknowledgment

This work has been supported by the International Atomic Energy Agency (IAEA) within the framework of the IAEA Coordinated Research Project (CRP) Number J02011 entitled (Improving the Security of Radioactive Material throughout its Lifecycle, Associated Facilities, and Associated Activities) under contract number EGY-23124 (GSM tracking system to enhance the nuclear security of SRSS during transport).

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