Application of Internet of Things Technologies for Automation and Quality Enhancement in Radiological Metrology

K. Sreekumar*, S. K. Jha, Jaison T John, M. Harikumar

Health Physics Division, Bhabha Atomic Research Centre, Mumbai 400 085

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**Corresponding Author Email: ksreekumar@barc.gov.in*

Abstract: Automation refers to the application of technology that reduces the need for human involvement [1]. It is being implemented in all aspects of modern life. Automation is also feasible in occupational radiation safety and surveillance programmes. One kind of modern automation is Internet of Things (IoT), defined as technologies with which devices with sensors, data processing units and software are linked together over internet or any other network [2]. Health Physics Units attached to various nuclear or radiological facilities all over the world are associated with radiological surveillance and protection of workers and environment. This paper briefs about application of various IoT techniques for automation in environmental and occupational radiological monitoring and surveillance programmes.

Keywords: Automation, IoT, MQTT, LoRa, dose rate

1. Introduction: The application of radiation sources and technologies are increasing with the advent of numerous beneficial applications for the society. Environmental and occupational radiological surveillances are the paramount requirement of any nuclear or radiological facility. The objective of these surveillance programs is to minimize hazards to the occupational workers, public and environment from handling radiation sources while deriving fruitful benefits. The Health Physics Units attached with various facilities across the world is mandated to ensure the safety and protection of workers and environment. The objectives of surveillance programme are to (I) protect the environment and worker against harmful effects of ionizing radiation (II) keep all radiation exposures as low as reasonably achievable and (III) ensure regulatory compliance and keep all radiation exposures to well within regulatory limits.

Radiation exposures are broadly classified into two category (a) External exposure, when radiation source is situated outside the body and (b) Internal exposure, when radiation source is situated within tissues and human beings are exposed. Radiation dose rate survey for measurement of ambient dose rate is the main method of external exposure surveillance.

Automation is a term for technology application where human input is minimized. There are infinite advantages of any automation process. The most important are (i) Increased Safety (ii) Increased throughput or productivity (iii) Improved quality (iv) Increased predictability (v) Improved robustness (vi) Reduced direct human cost and expenses (vii) Reduced cycle time (viii) Increased accuracy (ix) Relieving humans of monotonous repetitive work and (x) Increased human freedom to do other things. These advantages have important contribution in reducing radiation exposure and increasing safety in radiological installations.

Internet of Things (IoT) is a concept defined as technologies with which devices with sensors, data processing units and software are linked together over internet or any other network. Based on terrain and/ or requirements, different types of IoT techniques are utilized. Some of the most widely used IoT technologies are wide area

General Pocket Radio Services (GPRS) and local range networks. GPRS based IoT system uses telecommunication modules from third-party service providers. It is either based on Global System for Mobile (GSM) communication with Subscriber Identification Module (SIM) or Code Division Multiple Access (CDMA) with or without SIM. This has advantages of being very wide area coverage and limitation of high dependence on third part operators. On the other hand, long range private networks are for dedicated communication within pre-determined terrain or area. LoRa™ is among the most utilized private IoT networks. This has the advantage of user defined hardware and software modules as well as, independent of any third-party service provider.

There are other local area network IoT technologies like WiFi and Bluetooth that are used in systems for implementing short range connectivity. This paper briefs about application of both GPRS based and LoRa™ based IoT technologies for automation in environmental and occupational radiological surveillances programmes.

2. Development of GPRS based Indian network of environmental radiation tracking system

Outdoor external dose rate measurements are carried out for various purposes such as (a) Environmental baseline studies prior to operation of any nuclear or radiological installation (b) During operational stage to ensure that the radiation levels are within stipulated limits and the installations do not release any radioactivity to the environment (c) Radiation monitoring during Radiological Emergency situations where presence of radioactive substances or any air borne radioactive material in environment is anticipated (d) Mineral resources survey, especially for Thorium and Uranium resources and (e) Academic studies. There are different types of radiation survey meters available in this purpose. With the advancements in GPS technology like low power and compact embedded systems, Radiation survey meters for outdoor applications are designed with inbuilt Global Position System (GPS) receivers. Such systems have the provision of displaying or storing environmental dose rate data with GPS tagging. The system developed by Health Physics Unit, IREL (India) Limited, Manavalakurichi is a network of GPS tagged radiation survey meters interfaced with central server through GPRS mode of networking to display the real time dose rate data on maps or GIS based software interface.

2.1. Material and methods for GPRS based systems

The requirement was to develop a system of portable radiation survey meters with sensitive radiation detectors and integral GPS modules. The dose rate data with GPS data tagging is to be connected to the server installed at Health Physics Unit, IREL(India) Limited, Manavalakurichi with suitable IoT connectivity. The system developed was intended for pan India radiation monitoring and data communication to extend the application of the system to all nuclear and radiological facilities in the country. As GPRS network has extensive coverage and the network system is spreading across entire country, this mode of communication was adopted for the development of the system.

The objective was further enhanced to explore developing a few radiation survey meter combined environmental gamma spectrometer modules with GPS tagging and GPRS connectivity. The modules shall generate and GPS tagged dose rate data as well as ambient gamma spectrum for monitored location.

There are three different operating protocols available for GPRS based IoT applications. They are HyperText Transfer Protocol (HTPP), Constrained Application Protocol (CoAP) and Message Queuing Telemetry Transport (MQTT). Each method has advantages and limitations. A brief summary of the same is listed below [3-5].

Table 1. Brief comparison of different data sharing protocols over GPRS

HTPP	CoAP	MQTT
Advantages Widely supported and ubiquitous. Human-Readable data formats Enhanced data security Request-Response Model for web applications. Operates in Full-duplex, Bidirectional modes.	**Advantages** CoAP is specifically designed for resource-constrained devices and low-power networks. Binary format and efficient messaging. Supports multicast communication, allowing multiple devices to receive the same message. Request/Response model for synchronous mode of data transmission.	**Advantages** Efficient Publish-Subscribe Model for real time updates. Low Overhead. Low bandwidth. User defined Quality of Service. Better data security. Simplified middleware. Publish/Subscribe model for IoT uses.
Disadvantages High Overhead and inefficient for small payloads or frequent communication in IoT scenarios. HTTP relies on long-lived connections for real-time updates, which may not be ideal for constrained devices or unreliable networks. HTTP's request-response model may introduce latency, especially when multiple round-trips are required to fetch data or interact with web services. This latency may not be acceptable for real-time IoT applications.	**Disadvantages** Less Widespread Adoption. Limited Middleware. Reliability Challenges with unreliable networks. Security Considerations requiring additional layers. Less Interoperability with other protocols. Complex translation or adaptation layers may be required.	**Disadvantages** Efficiency varies with specific use cases. Relatively new concept for developers. Not as widely used/ supported as HTPP.
Typical applications Web-based uses. Security-Intensive Applications.	**Typical applications** Resource constrained systems including low power IoTs.	**Typical applications** Real-Time IoT Applications. MQTT is a reliable choice for large-scale IoT deployments, with the ability to handle numerous devices efficiently.

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Among these protocols, Message Queuing Telemetry Transport (MQTT) was chosen as preferred protocol for our IoT communication. This has the advantages of low band width and higher data density.

The detector used in the radiation survey meters is CsI(Tl) scintillator detector of size 10 mm x 10 mm x 10 mm, coupled with temperature compensated photo diodes was chosen for radiation detection and measurement. These detectors have sensitivity of approximately 80 counts per second per micro sievert per hour (cps/µSv h^{-1}). It has a good stability up 55˚C ambient temperature that is ideal for outdoor applications. The overall power requirement is also very less and can be sourced using batteries or solar panels.

Additional IoT linkage through WiFi mode was provided to connect each survey meter with a tuned android handset (mobile phone). This feature provided secondary readout and data logging. Hence the radiation survey meters could be used as portable backpack system, The block diagram of INERTS survey meter is shown in Figure 1.

As a part of prototype system development, five sensitive environmental radiation survey meters were fabricated and integrated with server at HPU, Manavalakurichi. The instrument has the resolution of 0.001 µSv h^{-1} and operating range up to 30 µSv h^{-1}.

Schematic diagram of Indian Network of Environmental Radiation Tracking System (INERTS) is shown in Figure 2.

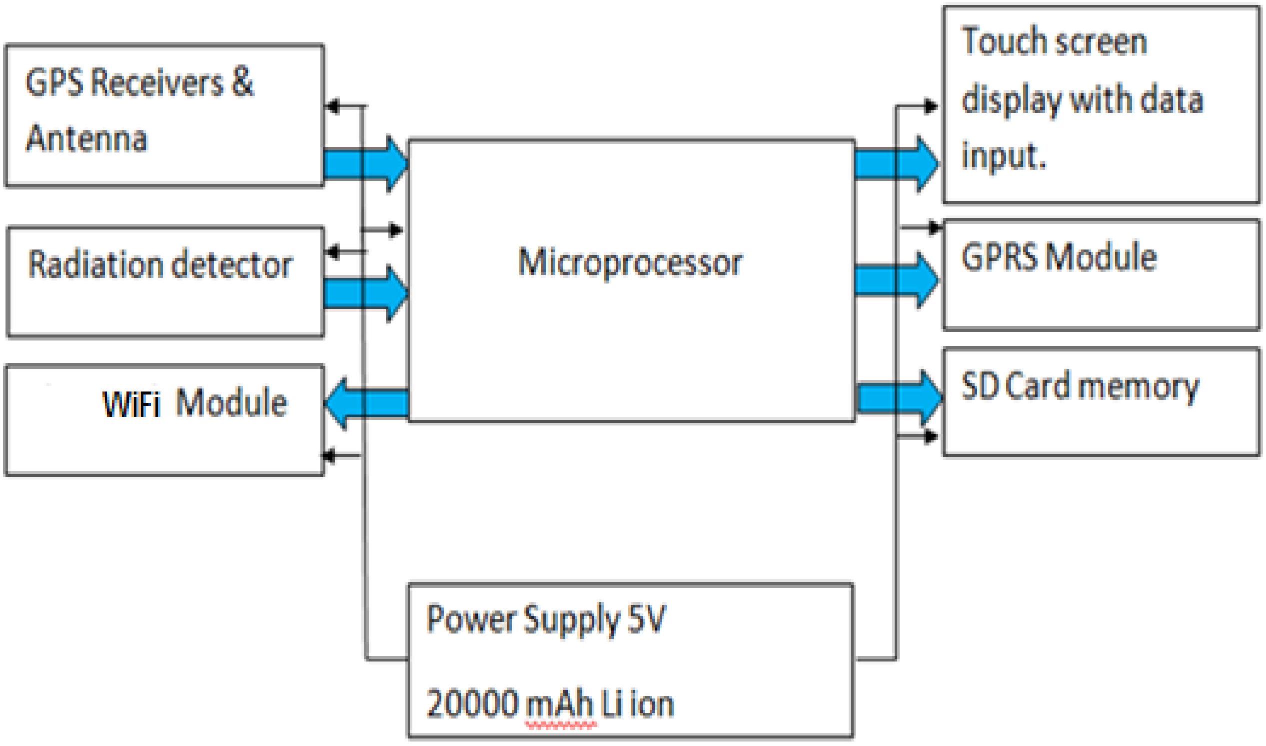

Figure 1. Block diagram of INERTS Radiation Surveymeter

Sensitive GPS module with 6-Channel receiver, u-blox 7 engine GPS/QZSS 1C/A and external antenna was used for incorporating GPS tagging to the environmental radiation data.

Image of INERTS detector module and survey meter are shown in Figure 3(A) and 3(B).

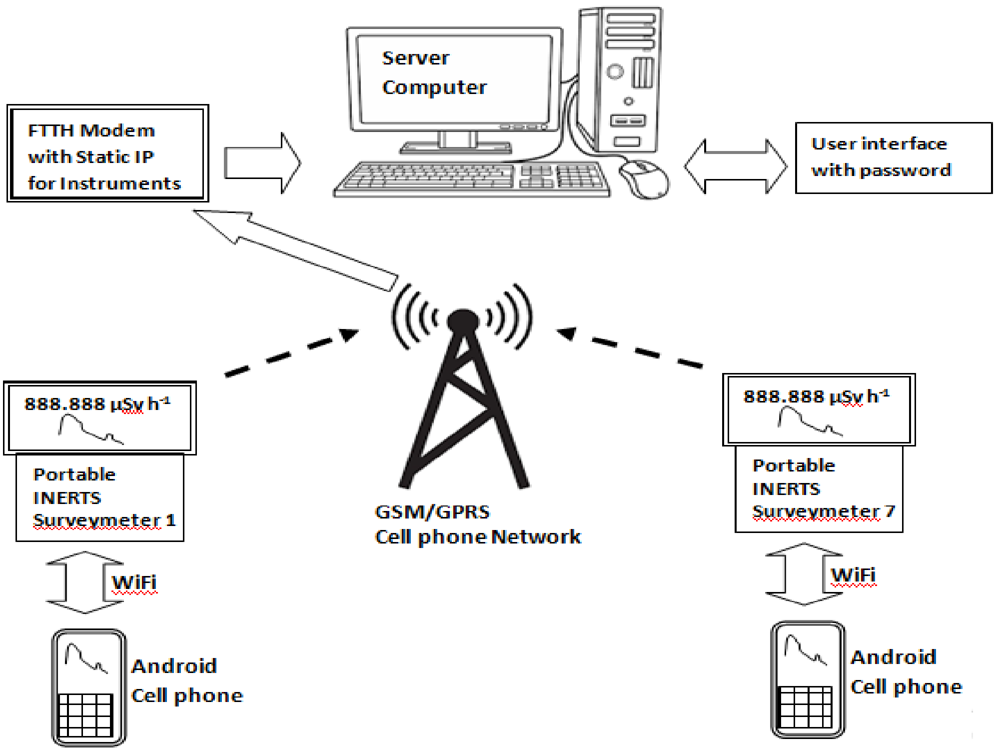

Figure 2. Schematic of Indian Network of Environmental Radiation Tracking System (INERTS).

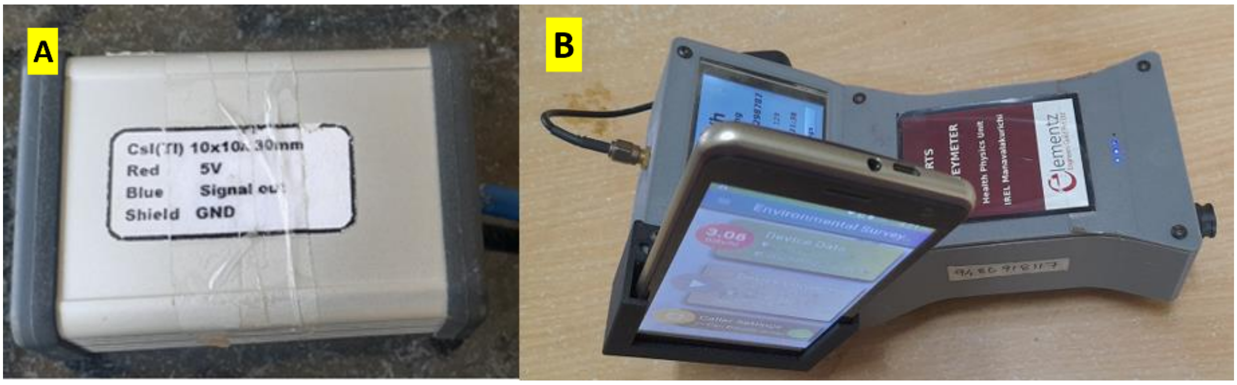

Figure 3. (A) CsI(Tl) detector module (B) INERTS Survey meter

The GPRS services by M/s Bharat Sanchar Nigam Limited was used for instrument connectivity with the server. The data generated by the instrument consisted of ambient Gamma Spectrum, dose rate ($\dot{H}p(10)$) , date & time, GPS coordinates and number of GPS satellites accessed.

Seven portable gamma spectrometers with radiation dose rate read out was also designed and fabricated using a more sensitive NaI(Tl) detector of size 25 mm x25 mm. This instrument can acquire and display ambient gamma spectrum, dose rate and GPS coordinates. Images of the same are shown in Figure 5.

The central server computer is installed at Health Physics Unit, IREL (India) Limited, Manavalakurichi. All the data generated by the portable field instruments are real time uplinked this server that has a Linux operating system (OS). The software interface for data acquisition and interface was developed using Python programming language. Both the OS and software development was done using open source software to make it adaptable across all platforms.

Date & Time	Status	Latitude	Longitude	cps	Dose rate µSv h^{-1}
09-07-2022 19:59	1	34.15835	77.58096	50	0.110
09-07-2022 19:59	1	34.15836	77.58097	48	0.110
09-07-2022 20:00	1	34.15836	77.58096	40	0.094
11-07-2022 14:48	1	34.14685	77.57451	30	0.068
11-07-2022 14:48	1	34.14685	77.57452	30	0.062
11-07-2022 14:50	1	34.14687	77.57446	28	0.060
11-07-2022 14:50	1	34.14687	77.57447	19	0.066
14-07-2022 13:44	1	33.22301	78.31491	57	0.121
14-07-2022 13:47	1	33.22298	78.31487	58	0.098
14-07-2022 13:47	1	33.22297	78.31487	41	0.095
15-07-2022 18:24	1	34.13869	77.54009	27	0.054
15-07-2022 18:24	1	34.13868	77.54009	31	0.056
17-07-2022 13:11	1	34.91456	76.79447	22	0.058
17-07-2022 13:12	1	34.91454	76.79448	29	0.061

Figure 4. Sample specimen of data generated by INERTS survey meter.

Figure 5. INERTS Gamma Spectrometer combined Radiation Surveymeter models

2.2. Data processing and application for GIS/ radiation mapping: The data generated by the Radiation Survey Meters and Portable Gamma Spectrometers were extensively used for radiation mapping of Kanyakumari and Kollam regions which is a part of Natural High Background Radiation Areas (NHBRA) in the country. To test the applicability of the system in different environmental conditions, radiation mapping of Ladakh region was also carried out. Images of the same are shown in Figure 6.

The radiation dose rate data generated by the INERTS survey meters are extensively used for generating GIS profiles. Radiation dose rate profile of NHBRA of Kanyakumari was done to test the system in different radiological conditions with wide variation in ambient dose rate as well as to quantify concentration of radioactive mineral Monazite which is the main contributor to the elevated dose rate in these locations. A specimen image of Arc GIS profile of external dose rate (µSv h^{-1}) is given in Figure 7. This demonstrates adaptability of data generated through IoT based radiation surveymeters for user interface applications.

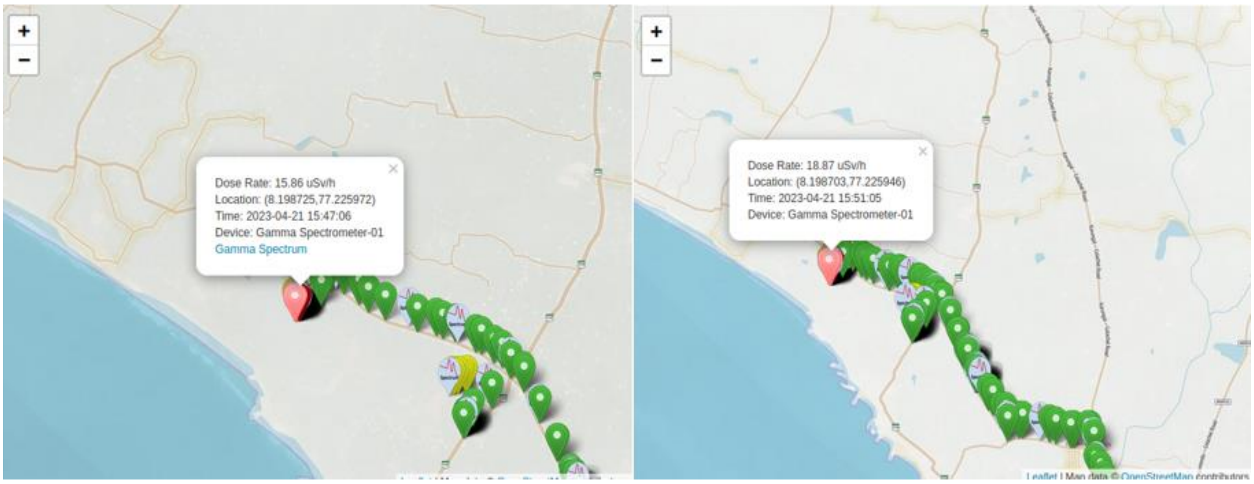

Figure 6. Radiation mapping of natural high background region of Kanyakumari

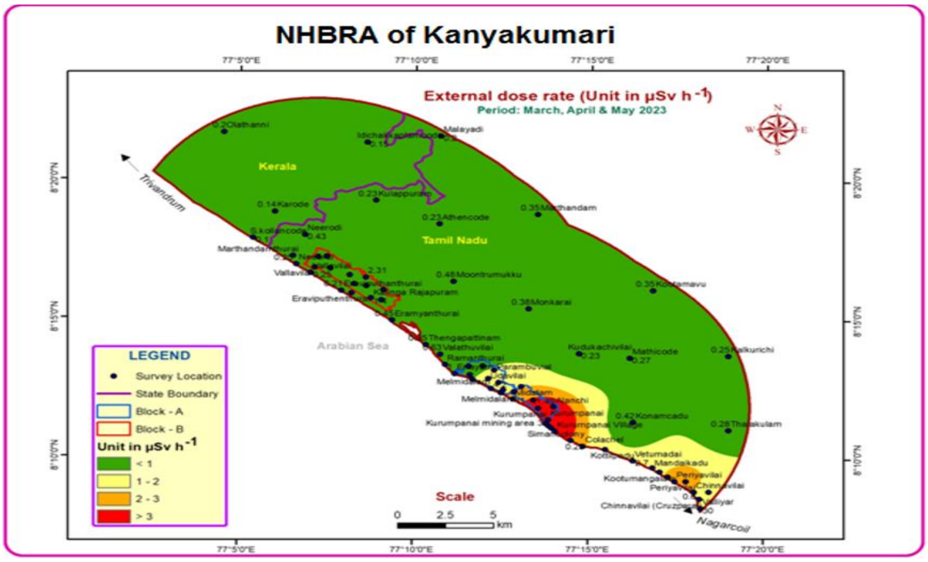

Figure 7. GIS profile of external dose rate at high background radiation area of Kanyakumari using IoT based surveymeters.

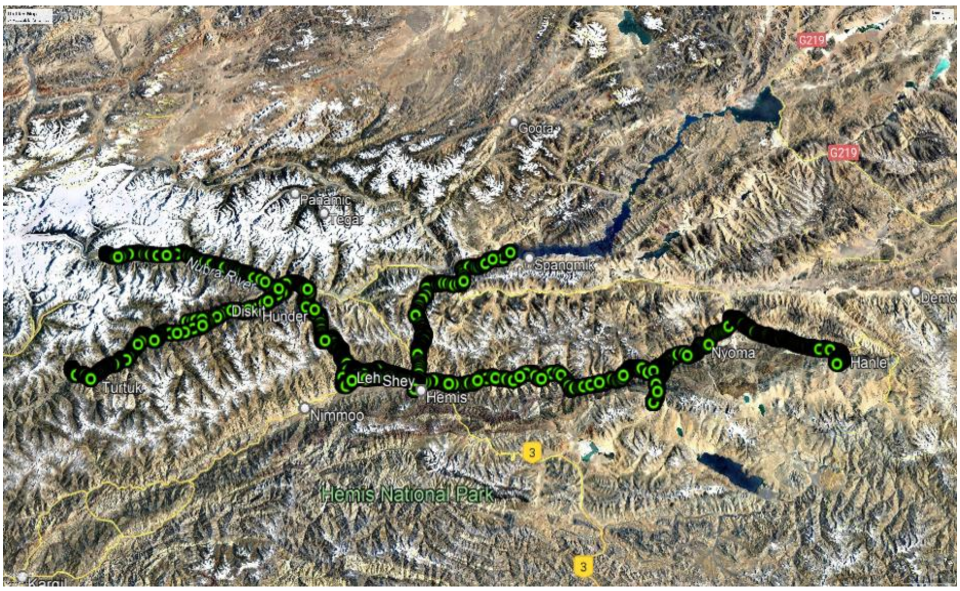

Figure 8. Radiation Mapping of Ladakh region

Radiation mapping of roads of Union Territory of Ladakh was done using INERTS surveymeter as backpack system. Real time monitoring and mapping of dose rate was done at most of the places, subjected to availability of GPRS signal.

3. Development of LoRa™ based integrated radiation monitoring system: External exposure monitoring which is an important aspect of occupational radiation protection in radiological facilities, is done by different methods. These methods include (a) Periodic radiation survey of workplaces (b) Installation of fixed Area Gamma Monitors and (c) Measurement of actual dose received by individual worker through use of active or passive dosimeters. Each methods has its distinct advantages over others and a combination of all methods are required for effective dose management of any radiation facility.

Periodic radiation survey and fixed location radiation monitoring are the two main methods for instantaneous assessment of radiation dose rate at workplace. The first method employs extensive use of human resources and later depends on the number of instruments installed at various work locations for accurate monitoring. Till date installing many fixed radiation monitors (Area gamma monitors) was impractical due to cost of instruments and difficulty in practically accessing each instrument for data collection or readout. Wired connectivity is often not feasible in large radiation facilities. The development of an IoT based Integrated system of fixed radiation monitors and accessing all through a single computer is made towards achieving better radiological monitoring and dose control at nuclear front end fuel cycle facilities. The Internet of Things (IoT) system based on LoRa™ transmitter working in Indian license free Industrial Scientific and Medical (ISM) frequency band of 865-867, 868 MHz is the most suitable module for interfacing with semiconductor-based radiation instruments. TEVISO 51 BG is a semiconductor-based radiation detector capable of measuring dose rate between 0.01 $\mu Sv\ h^{-1}$ to 100 $mSv\ h^{-1}$.

Teledosimetry or remote dosimetry is a concept of remotely measuring external dose received by a radiation worker. This tool is very effective for remote monitoring and control of doses in areas where high radiation exposure is likely. This manuscript describes the work carried out to develop a system of 15 network linked fixed area monitors and 5 teledosimeters to meet the requirement at Mineral Separation Plant, IREL (India) Limited, Manavalakurichi and to study the feasibility for adapting it for other larger nuclear and radiological installations.

3.1. Material and methods for local IoT based radiation monitoring system: The requirement was to develop a system with independent local IoT connectivity-based system where the requirement of GPRS mode of communication was not necessary. Instead, local networking options were studied for effectiveness and reliability. Various technologies like for Wireless Fidelity (Wi-Fi), Bluetooth, Zigbee, and LoRa were considered for our requirements. A brief comparison of different IoT techniques were made. Considering the relatively low volume of data, terrain profile with no line-of-sight configurations and presence of shielded walls between work areas and data receiver antenna, LoRa technique was the most suitable for IoT communication and a system using this mode of communication was developed.

Table 2. A brief comparison of different IoT techniques for local area network [6-8].

Features	**Wi-Fi**	**Bluetooth**	**Zigbee**	**LoRa**
Data Rate	High	Low to Mod	Low to Mod	Low to Mod
Frequency (India)	2.4 GHz, 5 GHz	2.4 GHz	865, 915 MHz, 2.4 GHz	865 MHz
Range	Short	Short	Short to Mod	Long
Power Consumption	Mod to High	Low to Mod	Low	Low
Network Topology	Varied	Varied	Mesh, Star, Tree	Star, P2P, P2MP
Data Security	Strong	Strong	Strong	Basic
Advantages	High data rates for data intensive uses. Ubiquitous and Wide availability. Supports multiple devices.	Versatile for personal area networking. Low to moderate power consumption.	Low power, suitable for battery driven devices. Mesh network for enhanced reliability. Strong security features with AES-128 encryption.	Exceptional low power and long-range coverage. Well suited for sensor- heavy applications. Cost- effective
Disadvantages	Limited range mainly for indoor use. Higher power consumption. High risk of interference in crowded bands.	Shorter range compared to Wi-Fi and LoRa. Moderate data rates High risk of interference in crowded 2.4 GHz band.	Limited range, typically up to 100 m indoors. Lower data rates compared to Wi-Fi. Relatively complex network setup.	Lower data rates compared to Wi-Fi Slower data transmission. Limited use cases outside of long-range IoT.

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TEVISO 51 BG is a semiconductor-based radiation detector with sensitivity 5 counts per minute per microsievert per hour (5 cpm per μSv h^{-1}) capable of measuring dose rate between 0.01μSv h^{-1} to 100 mSv h^{-1}. Images of LoRA module and BG51 are shown below.

Table 3. Technical specifications of LoRa™ transceiver

Transmitter Details	
Transceiver	1W E byte E220
Modulation	LoRa TM
Frequency	865-867, 868 ISM
Legal requirement	License free
Weight	3 g+ 10 g for 2.5 dBi antenna
Power: Standalone/ Transmitting mode	20 mW / 1W
Operating Voltage	3.7 V Dc
Range	Max 7 km, typical 3km
Data transmission	0.018- 62.5 kbps
Receiver	8 Channel LoRa WAN with 12dBi antenna
Dose & Dose rate Data refreshing	Once in 10 Second (Maximum)
Number of dosimeters/ area gamma monitors linked	Maximum 08 @ 10 second data refreshment. 128 @ 3600 second data refreshment

1

Table 4 Technical specifications of radiation detector

Model	Teviso BG 51
Type of detector & Sensitivity	Si PIN Diode & 5 cpm/(μSv h^{-1})
Size & Weight	30mm, 15mm, 7 mm & 2.2g
Power	<0.01W
Operating Voltage	5-15 V Dc
Measurement Range	
Dose rate	0.001-100 mSv/h
Dose	**0.01-100 v**

1

Figure 9. (A) LoRa™ module, (B) TEVISO BG 51

This system consists of 08 No of outdoor fixed location monitors, 07 No of Indoor fixed location monitors for work area monitoring and 05 No of portable Teledosimeter for individual dose monitoring purposes. Salient features of the system are given below.

3.1.1. Fixed Area Outdoor Monitors: These are standalone system designed for fixing at outdoor locations without power supply access. This system consists of a radiation measurement unit with sensitive semiconductor detector (Sensitivity: 5 cpm per μSv h^{-1} dose rate) integrated with LoRa

TM based IoT module. The LoRaTM module is made up of 1W Ebyte E220 series (865-867 MHz) transceiver with 5dBi LoRa antenna. The power supply for the same is provided through an internal 4000mAh Li ion battery and charged by 3W Mono crystalline solar panel. The entire system including radiation measurement unit, IoT module, battery and solar cell is housed in an ABS enclosure with IP65 protection standard. Radiation dose rate data along with battery status, enclosure internal temperature and humidity is transmitted once in every 60 minutes through LoRaTM modulation. The system consumes very low power (≤ 20mW) during non-transmission time and inbuilt power supply can power the system for two days in the absence of charging from solar panels.

3.1.2. Fixed Area Indoor Monitors: Indoor monitors are identical with outdoor devices except that solar panel is replaced with 1" OLED display for dose rate. This module also is fitted with 4000 mAh Li ion battery, charged through external C type USB port. This instrument is designed for installation at indoor locations where external power supply (230 VAC) is available. However, for locations with sufficient light illumination, provision to easily convert to solar powered system through externally mounted panel adaptors is made. Both outdoor and Indoor monitors are programmed to transmit averaged dose rate data every 60 minutes and has a sensitivity of 0.01μSv h^{-1} and upper limit of 100 mSv h^{-1}. The dimension of both the monitors are 22 cm x 21 cm x 6 cm. and weight approximately 0.8 kg without clamp attachment.

3.1.3. Teledosimeters: LoRaTM based IoT technology is adapted for real time dose monitoring of radiation workers at Monazite Mineral Separation Plant. Teledosimeters also uses sensitive semiconductor detector (sensitivity: 5 cpm per μSv h^{-1} dose rate) and 1W EByte LoRa module with internally mounted 3 dBi antenna. Internal 4000mAh Li ion battery is charged through a C-type USB port. Cumulative dose and dose rate are transmitted once in every 15 second. Teledosimeter has dimension 9 cm x 6 cm x 3cm and weight approximately 0.1 kg. Images of Outdoor and Indoor monitors are shown in Figure 10 (A) and (B).

Images of dose rate display of Indoor monitor and LoRa based Teledosimeters are shown in Figure 11(A) and (B) respectively.

3.1.4. Installation of fixed monitors and LoRa receiver gateway: Installation of all the fixed area monitors were done as per monitoring requirements. Seven indoor monitors are installed within Mineral Separation Plant locations, considering potential for presence/accumulation of Monazite rich material. All the eight outdoor monitors are installed at various important environmental locations. One outdoor monitor is specially installed over Intertidal zone at Kadiapattanam – Valliyar river mouth location where monazite rich sand is deposited. This location is known for high natural high radiation background ranging 20 – 60 μSv h^{-1}.

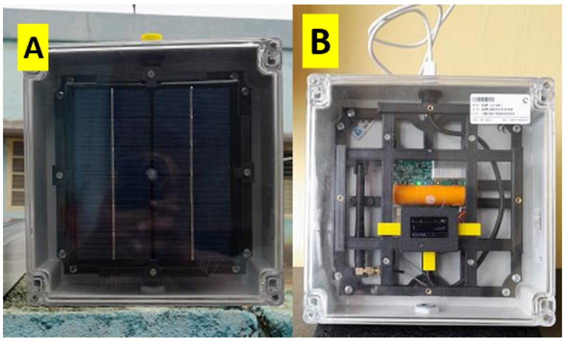

Figure 10. (A) Outdoor monitor with solar panel, (B) Indoor Monitor with OLED display

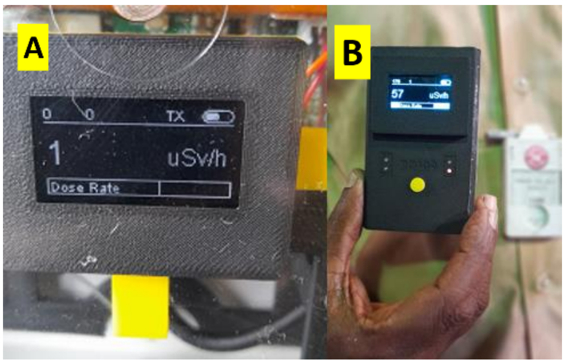

Figure 11. (A) Indoor monitor OLED display, (B) Teledosimeters

Location of installation of LoRa gateway for dose & dose rate reception is chosen in such a way to minimize structure or building shielding in between field instruments and receiver. Hence rooftop of tallest buildings was chosen for installation of LoRa Gateway system. It was operated continuously, powered by a 85Ah Lead acid battery connected with 65 W solar panel for charging.

The Health Physics Unit, where server computer is situated is approximately 80 m away from LoRa gateway installation. As this distance is on the higher side for Ethernet cabling, additional pair of 5 Ghz N300 Outdoor Wireless Bridge (802.11a) CPEs were installed between LoRa gateway and HPU server. Output of the Wireless bridge is fed to the server computer at Health Physics Unit. Among the Licence free ISM band of 865 -867 MHz, in-house frequency allocation of eight channels were assigned for fixed area monitors and mobile teledosimeters to avoid data interference. Installation at Valliyar river mouth and LoRa Receiver at tallest building top are shown in Figure 13(A) and (B).

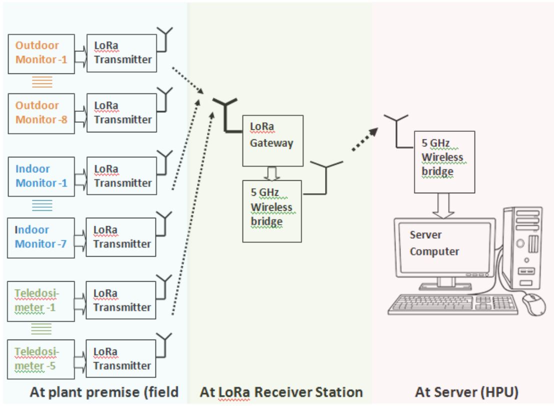

Figure 12. Schematic diagram of LoRa based Integrated Radiation Monitoring System

Table 5. In-house frequency allocation for LoRa™ based radiation monitors

Channel No	Frequency Hz	Device
0	865062500	Fixed Area Gamma Monitors
1	865402500	Fixed Area Gamma Monitors
2	865985000	Fixed Area Gamma Monitors
.3	865742500	Teledosimeters
4	866185000	Teledosimeters
5	866385000	Teledosimeters
6	866585000	Teledosimeters
7	866785000	Teledosimeters

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Figure 13. (A) Monitor at Valliyar river mouth, (B) Solar powered LoRa receiver

3.1.5. Data reception, logging, and analysis: The receiver unit consist of an 8 channel RAK Wireless LoRa™ Gateway attached with 13 dBi antenna. Radiation data from eight outdoor monitors, seven indoor monitors and five Teledosimeters are received through LoRa gateway and stored in the central server kept at Health Physics Unit. Software for the data reception and processing is done in PYTHON JANGO Programming on LINUX Operating System.

3.1.6. Data server and utility software: A common server is installed at Health Physics

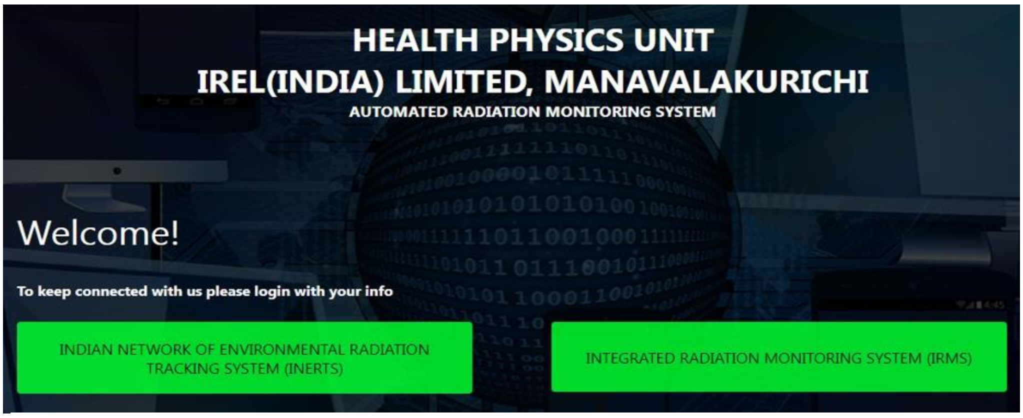

Figure 14. Welcome screen for combined INERTS and IRMS utilities

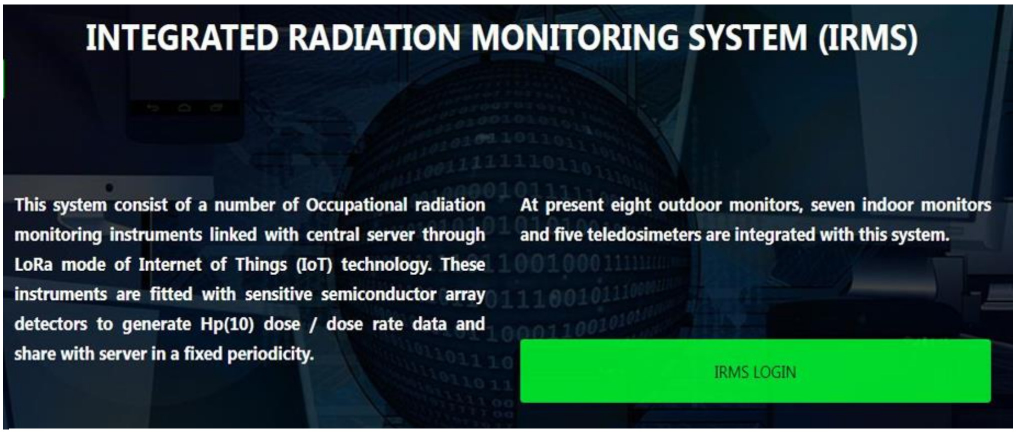

Figure 15. Login screen for IRMS

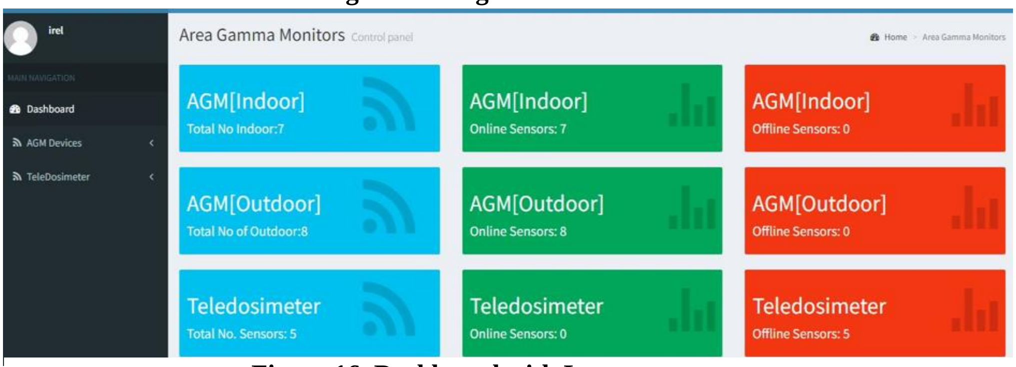

Figure 16. Dashboard with Instrument status

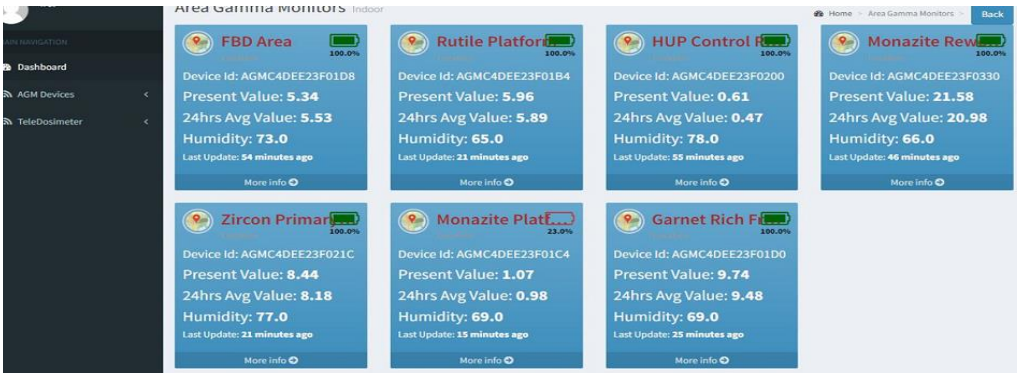

Figure 17. Status of radiation instruments

Unit to receive data from both MQTT based Indian Network of Radiation Tracking System (INERTS) and LoRa based Integrated Radiation Monitoring System (IRMS). Figures 14 and 15 shows welcome screen.

Further navigation to both features is password protected. On accessing Integrated Radiation Monitoring system, data from all the 20 radiation instruments are obtained. are obtained.

The radiation dose rate data can be fetched from the server and various functions like trend analysis, averaging, peak identification etc can be carried as required. Each instrument transmits dose rate data in every 60 minute and the same is recorded at the server. Outdoor monitors provide relatively consistent dose rate data since environmental variations are mostly negligible. However, location like Valliyar river mouth manifest dynamic dose rate profile during Monsoon months due to significant deposition and removal of Monazite mineral by strong sea currents. Images of dose rate profiles of different locations are shown in Figures 18 and 19.

Indoor monitors display ambient dose rate caused due to processing of Monazite mineral. Any increase in dose rate can be attributed to spilled or stagnant monazite rich material at plant locations or within equipment. A visual alarm is set to display readings in red if current hourly reading exceeds 1.5 times daily average value.

Similarly, data from teledosimeters consist of average dose rate and cumulative dose. This date is transmitted to the server in every 15 – 20 second. This data is very useful for understanding the dose rate profile of the radiation worker during the monitoring period. Dose rate profile of different work group are shown in Figure 20 and 21.

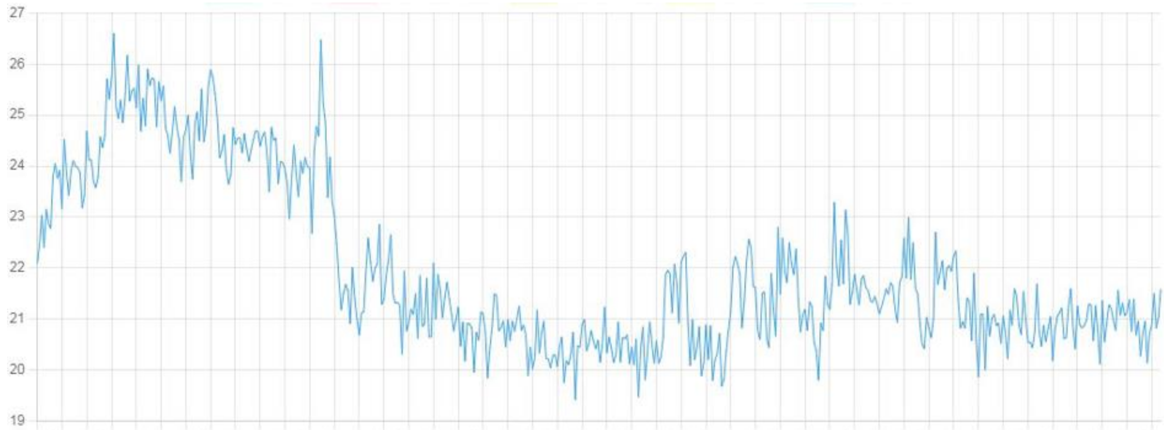

Figure 18. Observed variation of radiation dose rate (μSv h-1) at Valliyar river mouth

Figure 19. Observed variation of radiation dose rate (μSv h^{-1}) at Monazite reprocessing plant

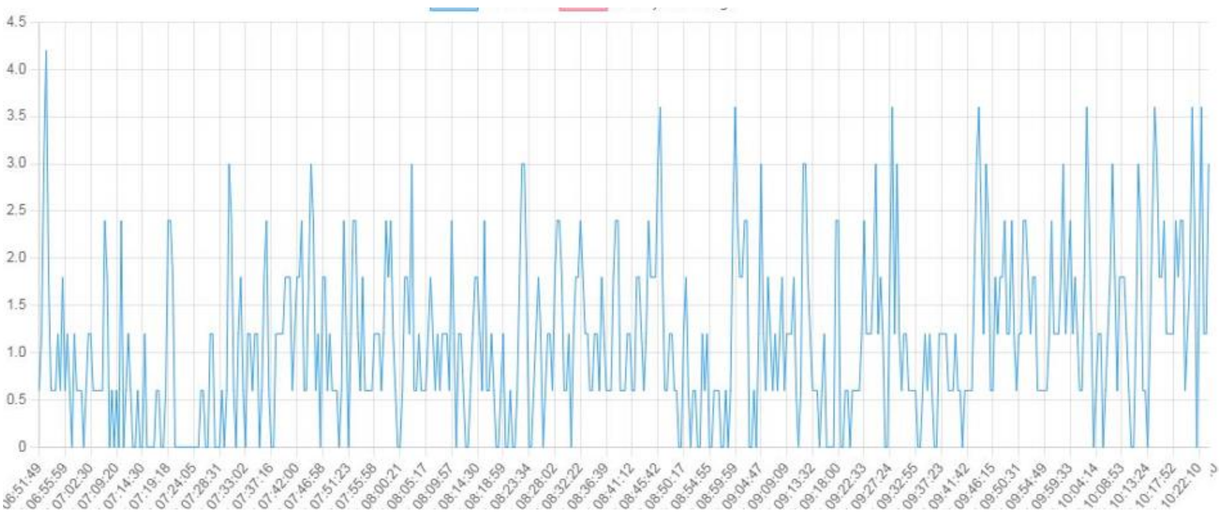

Figure 20. Observed radiation dose rate profile of HPU personnel on a monitoring day.

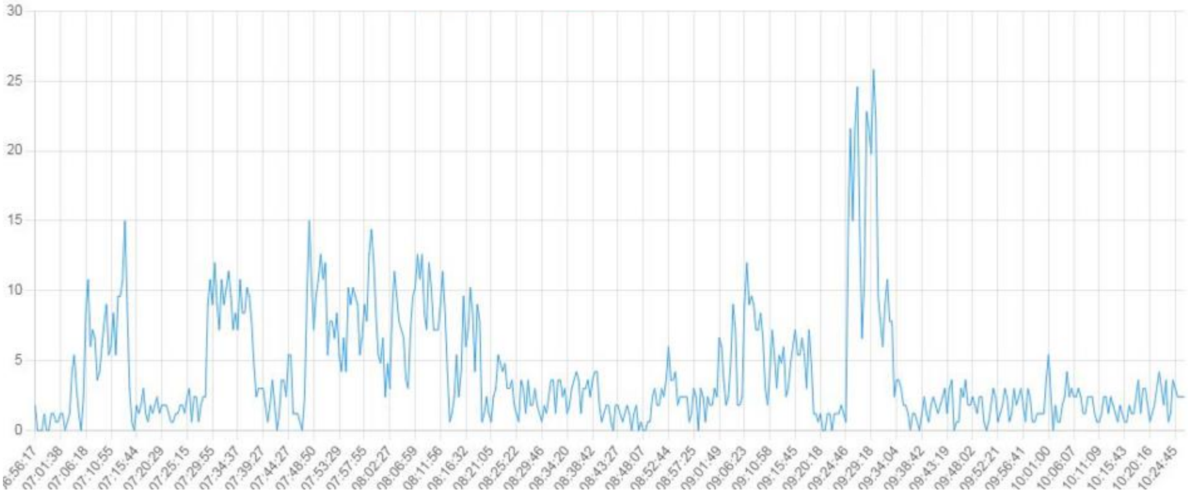

Figure 21. Observed radiation dose rate (µSv h^{-1}) profile of Monazite processing plant operator staff

Plant personnel spend more time within vicinity of Monazite rich material. Hence dose rate profile as well as cumulative dose received by them would be higher than other staff. Real time monitoring of their dose and dose rate is an effective tool for radiation exposure control.

4. Accuracy, error and failure analysis of the IOT based radiation measuring systems: All the radiation dose/ dose rate measuring instruments are calibrated with accuracy of ≤10%. Calibration of the fabricated instruments are done at an external facility with necessary accreditation. The estimated standard deviation (3σ) as well as least count for portable surveymeters is 0.001 µSv h^{-1} which is acceptable for environmental monitoring. The estimated standard deviation (3σ) as well as least count for fixed area monitors (both indoor and outdoor) is 0.1 µSv h^{-1} which also is acceptable for occupational monitoring whim facility. Accuracy of GPS modules used for INERTS Surveymeters is approximately 3 m and subjected to connectivity with satellites.

All the portable instruments are tested for shock, humidity, static electric and magnetic field for interference. All the components are shielded against radio frequency noises including system generated ones. The radiation detectors are temperature compensated up to 55°C. All the fixed area monitors and teledosimeters are specially designed against system generated RF noises as well as wide ambient temperature.

Allt portable surveymeters are inbuilt with internal storage device for primary data logging. Secondary and tertiary data logging is done independently at linked Android phone (WiFi) and at central server computer (GPRS- MQTT).

5. Conclusions: Internet of Things (IoT) techniques are very useful tool for automation. Effective utilization of these tools in radiological monitoring, with special emphasis to very wide area environmental monitoring (nationwide) and site specific occupational monitoring are briefed in this report.

Development and implementation of automation techniques is demonstrated for real-time monitoring of occupational and environmental radiation dose rate through effective adaptation of latest Internet of Things (IoT) concepts. GPRS based real-time tracking system was developed for environmental radiation dose rate mapping using CsI(Tl) detector with geo –tagging features. This was further enhanced with Spectrometric capabilities using NaI(Tl) detector. Application of IoT techniques is demonstrated by monitoring at Natural High Background radiation Areas in Kanyakumari, TN of southernmost India. For a comparison the Ladakh region of northernmost India was also monitored and mapped.. Portable Gamma Spectrometer Radiation Survey meter system with sensitive spectroscopic NaI(Tl) detectors and geo –tagging capability for real-time monitoring were also designed, fabricated, tested and demonstrated.

In addition to above, LoRa based IoT system was developed for real-time radiological monitoring of plant and premise locations with semiconductor radiation detector of dose rate measuring range between 0.01μSv h^{-1} to 100mSv h^{-1}. This included indoor and solar powered outdoor monitors; the latter is useful for remote location monitoring where power source is not available like coastal or unmanned areas. LoRa based IoT system was further used for developing Tele-dosimeters for real-time monitoring of external dose received by a radiation worker. This tool is for effective monitoring and controlling doses during high dose consuming jobs. The indigenous software developed for interface of these automation systems is also illustrated. This multiple types detectors and systems interface using IoT automation methodology is a unique developmental work that has not been reported worldwide in radiation monitoring applications. This developmental work can find numerous applications in various radiological facilities with challenging monitoring requirements.

Application of IoT concepts to the radiological monitoring has brought a measurable level of automation and improvement within. Important radiation instruments are in real time interface with the computer and measured parameters are analysed continuously. Various data analysis techniques like mapping, GIS Profiling, trend, alerts, reporting etc are easily done without any manual data input. Monitoring of radiological parameters at remote or difficult locations are made possible by exploring wireless data transmission, either through GPRS or LoRa devices. Measured parameters are also monitored at different hierarchy levels for better assessment.

The developments brought forward in this manuscript would enhance radiological metrology and bring in appreciable level of automation in different radiations safety and monitoring facilities and applications to meet occupational and environmental radiological measurements.

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