

# TRACKING RADIOACTIVE MATERIALS IN SEA TRANSPORTATION BY RFID TECHNOLOGY

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## Abstract:

*The demand for radioactive materials has been increasing over the last five decades, and therefore it is to be expected that the need for radioactive materials transportation shall also increase. The Radio Frequency and IDentification (RFID) technology has already made progress in this field and become the most widespread way to track and trace radioactive cargo. The easy installation, simple and fast data transfer from the sensor through RFID transponder, along with compactness and quality of the sensors provide a safe and easy way of using this technology in transport of the radioactive materials. A variety of sensors, such as temperature, radiation, speed, earthquake, (Differential) Global Positioning System (D)GPS, etc., are the key, but not the only one part of the complex system that is responsible for safe transportation of radioactive goods. A large number of parameters that must be monitored at the same time, as well as the simplicity of the system, are strengthened by using the appropriate RFID software. By means of this software, the operator has insight into the condition of the radioactive material inside the container without the risk of exposure to radiation, and without compromising the safety and security of the data exchange at any time. By using the latest-generation crypto tools, security has been guaranteed.*

## Keywords:

*radioactive materials, sea transportation, tracking and tracing, RFID technology.*

## INTRODUCTION

Today nuclear power provides 10% of the world's electricity. Due to the climate change, 80% of all electricity will need to be clean and low carbon by 2050 [1]. Therefore, nuclear capacity should be considerably increased in order to meet climate goals. Russia, India and China are currently leaders in expanding nuclear power production. For instance, China has nine reactors under construction now. Finland, United Arab Emirates, Belarus, Bangladesh and Turkey are also building new reactors. Currently, in total 450 nuclear power reactors operate worldwide.

Plans for increasing nuclear capacity are always connected with huge and high-risk investments. Small modular reactors make these plans more feasible and allow combining

nuclear power with renewables, i.e., sources of energy that are not depleted by use, such as water, wind or solar power. The environmental consciousness is generally rising and it becomes evident that energy need could not be satisfied in the future by sole use of coal or natural gas. Besides, for producing electrical power, nuclear energy is used for variety of research, industry, agriculture, and medicine purposes.

With increase of nuclear capacity worldwide, it is to be expected that the need for radioactive materials (RAM) transportation will increase. Thereby, sea transportation will undoubtedly play an important role in satisfying irradiated nuclear fuel, plutonium and radioactive waste transportation requirements in the upcoming period [2].

In this research article, we will be focused on literature review in the field of RAM transportation by means of sea, road and rail transport (Section 2). Particular emphasize will be given to tracking RAM cargo during its transportation or transshipment. An overview of the ARG-US project achievements, when it comes to tracking and tracing RAM in road and rail transportation, will be given (Section 3). After that, an attempt to conceive a similar model of RAM tracking in sea transportation will be done (Section 4). At the end, some conclusion remarks and directions for further research work in the field will be given (Section 5).

## **1. LITERATURE REVIEW**

There is a scarcity of research articles on nuclear cargo transportation, which are available online. Below are presented some of the articles, which have been found after an extensive web search. Legislative framework of maritime transportation of irradiated nuclear fuel (INF), plutonium and radioactive wastes together with widely expressed concern that an accident may occur to a ship carrying such cargo has been studied in [2]. The same study reviews the legal issues associated with the right of emergency access to a foreign seaport by a ship transporting nuclear materials. It also considers whether seabed characteristics should be assessed in determining the routing of nuclear cargo ships, bearing in mind that ocean floor topography and sea water depth will be crucial in determining whether recovery of nuclear materials would be practicable in the event of sinking of a ship. The description of ship carrying nuclear cargo construction requirements has been given in [3]. This paper presents INF Code requirements due to the ship's construction, fire safety measures, electrical power supply, cargo stowage and segregation, emergency planning and security measures. World Nuclear Transport Institute (WNTI) has published a fact sheet on the transport of nuclear fuel [4]. This study gives relevant data on the nuclear fuel cycle, front-end operations, fuel fabrication, reprocessing, transport packaging, sea transport, purpose-built vessels, etc. A model of response in the case of radioactive cargo transportation in Japan has been presented in [5]. The authors have given in this reference an overview of the tracking system for radioactive material transport including sensor unit, communication network, central monitoring center and sub-terminals, which provide trend viewer, abnormal situation detection, current situation and next step during the shipment. The authors of the references [6;7;8] have given description of applying Radio Frequency IDentification (RFID) technology in nuclear material management. They have provided prototype tag design and production, prototype application software including graphical user interface and preliminary test results in terms of read range, sensor performance, memory read/write, seal sensor, battery life, etc. It is worth to mention within the context that reference [9] gives a general insight in RFID technology and its applications. The authors of the reference [10] have dealt with mathematical modeling and simulations, based on special

tran-function theory, in estimating temperature of plutonium during its transportation. The authors of [11] have investigated efficiency of detectors for intercepting illicit trafficking of fissionable material in container cargo in maritime transportation. They have suggested tagged neutron inspection system in addition to container content X-ray scan, etc.

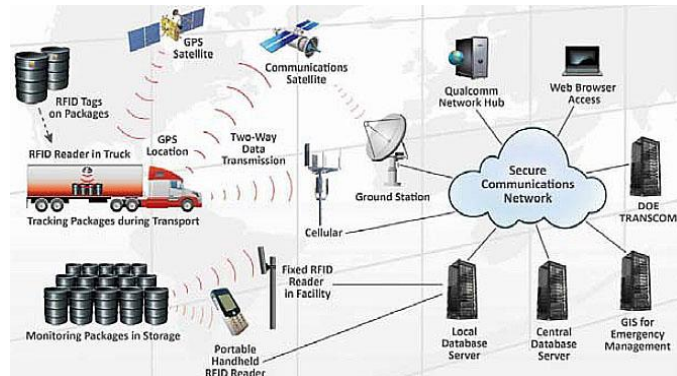
## 2. TRACKING RAM IN ROAD AND RAIL TRANSPORTATION

In 2008 Argonne National Laboratory (Chicago, Illinois, USA) Packaging Certification Program (PCP) team has developed RFID tracking and monitoring system for the management of RAM packages during storage and transportation [12]. This system, called ARG-US, is composed of appropriate hardware modification, application software, secured database, protected web access, and irradiation experimental measurements. The B fissile material drums (models 9975, 9979 and ES-3100) certified by US Department of Energy and US Nuclear Regulatory Commission have been used for testing the prototype. The demonstration of the system successfully integrated Global Positioning System (GPS) for vehicles and railway wagons positioning, including their RAM cargo, satellite and cellular General Radio Package Service (GPRS) wireless communications, the RFID tags attached to the RAM drums, and Geographic Information System (GIS) technology in geo-fencing purposes [13], etc. The RFID tags and GPS technology in combination with GIS enable dedicated software to trigger a response when a mobile device enters or leaves certain geographical area. The RFID in combination with GPS generate an alarm in the case of an incident with the RAM drums. Figure 1 gives an overview of the ARG-US prototype and associated field experiment. The fifty authorized stakeholders across the country of Illinois (USA) have observed the demonstration via secured internet access.

**Figure 1. a) ARG-US sensors' unit sealed at each RAM drum (Source: [13]) Scheme of ARG-US RFID monitoring and tracking RAM drum packages during storage and transport (Source: [12])**



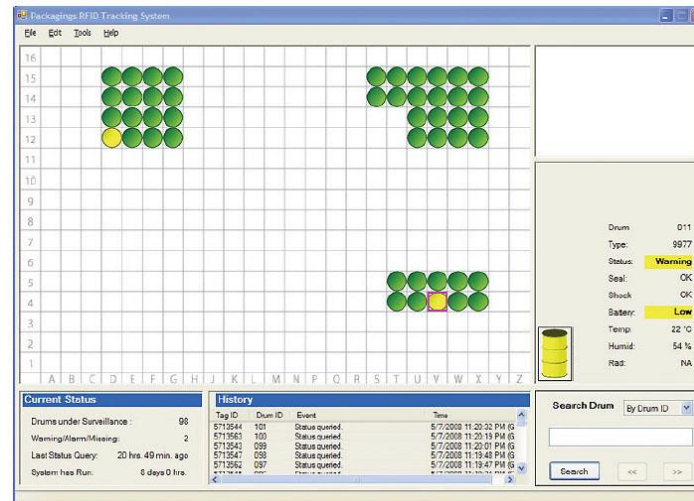
a)



b)

Firstly, experiments have been made with road transportation of a vehicle with 14 RAM drums along the route Chicago (Illinois) to Augusta (South Carolina). Sensor data were updated every 10 minutes, while several incidents of seal (i.e., loosening the drum bolts) and shock sensor violations were observed. At two mountain spots loss of satellite/cellular connection has been noticed. In addition, an incident with low battery level at sensors' unit attached to the RAM drum has been indicated (Figure 2).

**Figure 2. The ARG-US project graphical interface: round symbols represent RAM drums (Source: [12])**



The RAM drum marked yellow indicates a potential danger since battery is low at the moment. A drum marked red means serious danger, while a drums marked green indicates that everything is in order and there is no danger of an incident. The system tracks the drums in road transportation in close to real time. After these experiments in transportation of RAM cargo, a series of experiments at Argonne (Chicago, Illinois, USA) radiological facility has been realized across the RAM drums storage areas. Two layers of network for tracking and tracing stored RAM drums have been set: a multi-sand wired one as the first layer based on Ethernet, and the second one based on wireless network. Blink sensors have been used as wireless sensors that communicate only upstream with the Remote Area Modular Monitoring (RAMM) infrastructure nodes. They enable fast connection to the existing wireless sensor network (WSN). A digital video camera, or optical sensor, has been also incorporated into the RAMM platform. More about these second term set of the ARG-US experiments can be found in references [13;14;15].

Due to the lack of research articles when it comes to tracking RAM drums as single items in sea transportation, we have used the experiences from the ARG-US project realization to propose a model for RAM cargo tracking in marine transportation. Prior to the presenting the model, we have given a short overview of some structural requirements that ships for transportation of nuclear cargo have to comply with, in order to ensure safe RAM transport.

### 3. A MODEL FOR TRACKING RAM IN SEA TRANSPORTATION

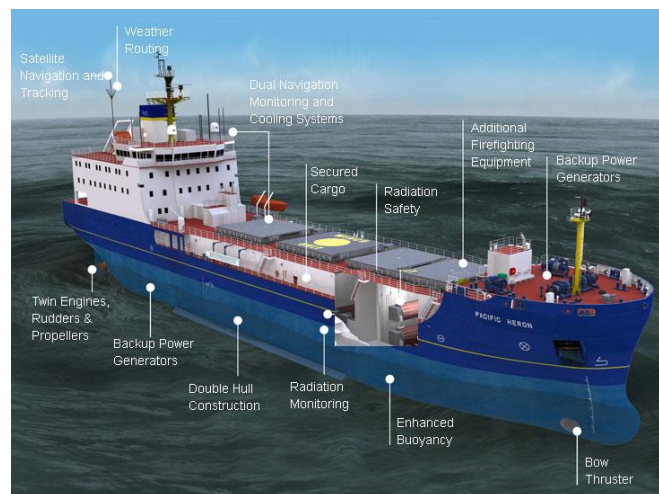
The International Maritime Organization (IMO) has introduced the elective Code for Safe Carriage of Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes in Flasks on Board ships, or so-called INF Code, in 1993 [3;4]. This Code complements International Atomic Energy Agency (IAEA) Regulations. The INF Code has been adopted in 1999 and become mandatory in 2001. It covers ship design, construction and equipment. It also included

advanced safety measures for ships carrying spent fuel, Mixed Oxide (MOX) fuel and vitrified high-level waste. The requirements for ships carrying nuclear cargo are as follows:

- Double hull around cargo holds, plus high resistant structures between hulls;
- Hull's firm anti-collision construction;
- Double safety-required equipment for navigation, communication, cargo control and monitoring, electrical and cooling systems, so that the second system could be used in the case of need;
- Satellite navigation, tracking and tracing, so that the ship automatically transmits its position in close to real time to a control center;
- Extra fire detection and fire fighting equipment including a hold flooding system, so that all holds could be completely flooded, while the vessel remains its buoyancy;
- Twin engines, rudders and propellers which operate entirely independently;
- Bow thrusters to provide higher level of maneuverability at slow speed, etc.

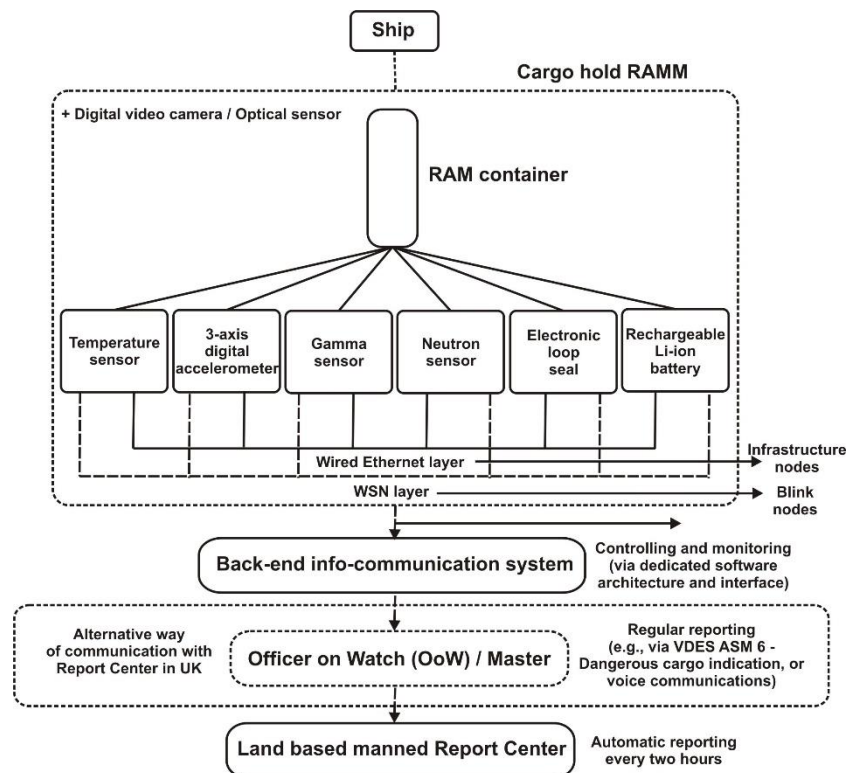
These purpose-built vessels have been used to transport fissile materials between Japan and Europe (United Kingdom and France). They are owned by Pacific Nuclear Transport Limited (PNTL), TN International, and a Japanese consortium. PNTL is the most experienced company for transportation of nuclear cargo at world scale. Up to now, it has covered more than five million miles without an accident. These ships usually have crew that is about two to three times larger than crew on chemical tankers of a similar size. Besides, navigating and engineering officers commonly hold certificates of competence for a higher rank than the one they serve. All PNTL ships meet the international standards and requirements of the relevant authorities [16]. In Figure 3 are shown main structural areas of a PNTL ship with a transversal cross-section of a nuclear cargo hold.

**Figure 3. Scheme of main structural areas of a PNTL vessel (Source: [16])**



Security is a top priority for ships carrying nuclear materials. Shipments must comply with coastal state requirements, as well as physical protection measures developed by the IAEA and IMO. Since in the focus of this paper is tracking and tracking RAM via RFID in sea transportation, we have tried to make a compilation of results and experiences from ARG-US project, and available online literature sources in this domain and propose a framework of an appropriate info-communication model (Figure 4). All PNTL ships have satellite navigation and weather routing equipment, as well as tracking equipment. Such systems enable these ships to follow the safest route and avoid severe weather patterns. Ship's position is monitored at any stage of her voyage. The voyage monitoring system automatically reports the vessel's latitude and longitude, speed and heading every two hours. If a message is not received by the report centre within a pre-determined time, PNTL's emergency response system is automatically activated [17]. If a ship accounts difficulty, trained and fully equipped PNTL emergency team is 24 hours on stand by to offer assistance. All emergency arrangements are in keeping with IAEA regulations [18]. Special monitors in the holds of each PNTL ship would provide information about the status of the cargo to a salvage team.

**Figure 4. Model of a nuclear cargo ship's communication system with manned Report Center (Source: Own)**



We have assumed that each ship's cargo hold is treated as a Remote Area Modular Monitoring (RAMM) sub-system connected with central monitoring system on board refereeing to ARG-US project attainments [6;7;8;13;14;15]. A digital video camera or optical sensor might be incorporated into each RAMM (RAM cargo hold). The RFID active tags attached to each RAM drum's bolt contains following sensors: temperature, 3-axis digital accelerometer, gamma sensor, neutron sensor, electronic loop seal and rechargeable Li-ion battery. All these sensors are connected with monitoring system via two-layered network, i.e., via wired Ethernet and wireless network for security purposes. Due to [19] ships carrying RAM cargo are fitted with



an automatic voyage monitoring system which transmits detail of the vessel's position, speed and heading to the Report Center (Barrow, UK) every two hours. These transmissions are performed automatically and without any intervention of the crew. If a message was not received at the allotted time the Emergency Response System would be activated. Further in [19] is stated: "It is probable that the transmission system would be based on, or similar to, the widely used Inmarsat C communication system which uses geo-stationary satellites positioned over the equator to receive and transmit the data." As an alternative, one can conjecture that Officers on Watch (OoW) and/or Master should monitor and control cargo holds through back-end info-communication system with the appropriate software architecture and interface. In addition, they might be responsible for regular reporting to the Report Center. If we assume that VHF Data Exchange System (VDES) is used for this purpose, then the reports should be sent via Application Specific Message (ASM) 6 (dangerous cargo indication + following communication) to the land based control-report center. The ASM 6 contains the information as: MMSI, flag, unit of quantity of dangerous cargo, code under which cargo is carried, BC class, IMDG class, and like [20]. Within the context, it is important to emphasize that mandatory reporting from ships is usually encapsulated into ASM, while Maritime Service Portfolio (MSP) cover a number of Vessel Traffic Service (VTS) related and other services [21]. Additionally, possibilities of using Iridium GMDSS [22] should be analyzed in the forthcoming research work in this domain. Apart from the proposed model based on the assumptions, through further research work some efforts should be made to identify exact extraterrestrial communication channel(s) and method(s) of (automatic) reporting, used as a bidirectional link between ships carrying nuclear cargo and ground based (control) report center(s).

#### 4. CONCLUSIONS

The paper proposes a model of communication between a ship carrying nuclear cargo and land based control center in sea transportation. The model is based on the experiences from ARG-US project being realized during ten years period (2008-2018) in Argonne National Laboratory (Chicago, Illinois, USA). Conceiving and designing a model has been supported by PNL information available on their official website. After an extensive search of the web, it can be concluded that online literature sources in this field are scarce. Further investigation should go in two directions: (a) exploring data transfer between sealed and tagged RAM drums and monitoring system on board ship, and (b) exploring in more detail communications between the ship carrying nuclear cargo and (control) report center ashore. Due to the lack of available information, we can only assume which form of data exchange and which communication channels are used. We have conjectured that ASM 6 reporting method within VDES might be used, but it might be also Inmarsat C, Iridium GMDSS, or some other extraterrestrial communication mode for providing safety and security at sea. This is to be explored in some more detail through the following research work.

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