

SECURITY DURING THE TRANSPORT OF NUCLEAR AND OTHER RADIOACTIVE MATERIAL

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Abstract

Since 2013, Argonne National Laboratory (Argonne) has conducted week-long training courses on security during the transport of nuclear and other radioactive material. The courses have been convened annually at Argonne, except in 2020 and 2021 because of COVID-19. The objectives of the transport security courses are to help participants gain a working knowledge and understanding of the United States and international requirements and recommendations for security during all modes of transport. While COVID-19 prevented travel, it also provided opportunities to explore electronic delivery platforms using advanced learning tools, including web-based apps for categorization of materials and transport security plans; geofencing and extended-reality scenarios for transport security and emergency response exercises; and interactive audience survey systems. These new tools should greatly enhance future training on security for packaging and transportation of nuclear and other radioactive material in nuclear fuel cycle operations.

1. INTRODUCTION

The U.S. Department of Energy (DOE) Packaging Certification Program, Office of Packaging and Transportation, Office of Environmental Management has sponsored a training course on security during transport of nuclear material (NM) and other radioactive material (RAM), conducted annually by Argonne National Laboratory (Argonne) since 2013. The original pilot course covered both international and U.S. domestic transport security; in later years, the course was divided into two separate, week-long courses, designated as NP-710: Nuclear and Other Radioactive Material Transport Security – U.S. Domestic, and NP-711: Nuclear and Other Radioactive Material Transport Security – International. The objectives of these two courses are to help participants gain a detailed working knowledge and understanding of the regulatory requirements and international recommendations and guidelines for security during the transport of NM and other RAM by all modes of transport. More specifically, NP-711 addresses the recommendations and guidance from the International Atomic Energy Agency (IAEA) and the international regulatory requirements and recommendations from relevant international and regional modal transport organizations, whereas NP-710 addresses the requirements of U.S. government agencies and regulatory authorities such as the Nuclear Regulatory Commission (NRC), Department of Transportation (DOT), Department of Homeland Security (DHS), and DOE. Both courses provide guidance on how to develop transport security systems by following a graded approach and applying modern technologies; how to develop transport security plans (TSPs) that satisfy regulatory security requirements; how to apply rules of engagement for escort, guard force, and emergency response personnel; and how to communicate with stakeholders and the public during emergencies, among other topics. Both courses incorporate hands-on exercises involving TSPs, readiness reviews, and corrective actions; use of audience participation systems to enhance dialogue; and a field exercise using the ARG-US remote monitoring systems to track a mock shipment with “staged incidents.” Both courses also make extensive use of tabletop exercises to facilitate learning through role-playing, discussions, and group reports [1]. The flowchart of the one-week transport security training courses, shown in Figure 1, is applicable to both NP-710 and NP-711.

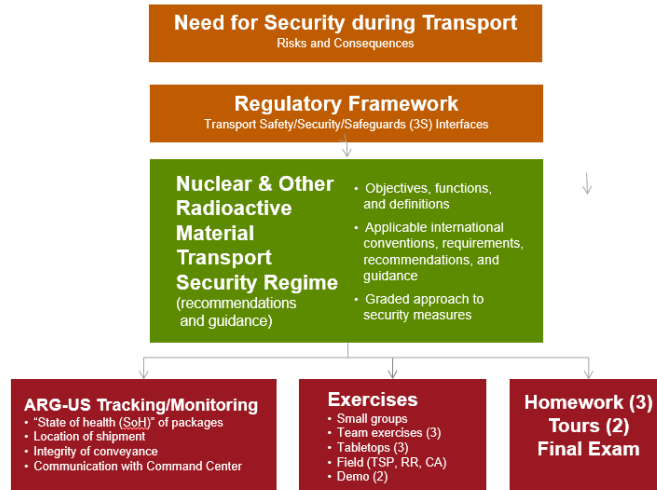


FIG. 1. Flowchart of the Transport Security Training Courses (NP-710 and NP-711)

Because of COVID-19, the transport security courses were not convened at Argonne in 2020 and 2021. While COVID-19 prevented travel and personal contact, it also provided opportunities to explore electronic delivery platforms using advanced learning tools, such as web-based apps for categorization of materials and TSPs and transport emergency response exercises, and interactive audience survey systems [2]. Other web-based apps used in the training courses include geofencing for the ARG-US TRAVELER [3, 4] for tracking and monitoring nuclear cargo conveyances and extended virtual-reality scenarios for transport emergency response exercises [5, 6]. In this paper, we provide a summary of lessons learned from previous courses on transport security and transport emergency response, and highlights of recent development and enhancements, emphasizing web-based apps for categorization of materials and TSPs; geofencing and geographic information system for the ARG-US TRAVELER; extended virtual-reality scenarios for transport emergency response exercises; and interactive audience survey systems. These new tools should greatly enhance the effectiveness of training on transport security and emergency response for nuclear and other RAM in the future.

2. LESSONS LEARNED

Table 1 lists the transport security and emergency response training courses convened at Argonne from 2013 to 2023. Participants and students in these courses, all participating in person at Argonne (except for the pilot of the transport emergency response course held virtually in December 2021), came from countries in North America, Europe, the Middle East, and Asia. Course participants have included representatives from regulators; consignors, carriers, consignees, and shipping brokers; and State/regional inspection, escort, enforcement, and response personnel. Course lecturers have included experts from U.S. domestic organizations, including the NRC, DOE, and the Federal Bureau of Investigation; and from international organizations, including the IAEA, World Institute for Nuclear Security (WINS), World Nuclear Transport Institute (WNTI), and Risk Management Solutions. Over 110 students have participated in the three training courses to date.

The first pivotal change in the transport security training course came after the pilot course in 2013. The feedback from the participants was that combining international and U.S. domestic transport security provided too much information for coverage during a one-week training course. Therefore, the follow-on training courses were split into two separate courses: U.S. domestic transport security courses convened in 2015, 2016 and 2019, and international transport security courses convened in 2017, 2018, and 2023. By reducing the scope of coverage in the two training courses, more room was available for classroom discussion and the interaction was also enhanced by using an electronic audience participation system that provided anonymous voting (e-voting) on sets of questions designed to elicit responses on various topics from the classes. Radiofrequency identification (RFID) key fobs were used in the classroom discussions in all in-person training courses at Argonne between 2014 and 2019, until the COVID-19 pandemic, during which web-based systems became mainstream in education worldwide.

TABLE 1. ARGONNE TRANSPORT SECURITY AND EMERGENCY RESPONSE TRAINING COURSES (2013–2023)

Topic	Date
U.S.-Domestic and International Transport Security	December 2013
International Transport Security	December 2014
U.S.-Domestic Transport Security	June 2015
U.S.-Domestic Transport Security	August 2016
International Transport Security	September 2017
International Transport Security	September 2018
U.S.-Domestic Transport Security	September 2019
Transport Emergency Response	December 2021
International Transport Security	December 2023
Transport Emergency Response	August 2023

The second pivotal change in the transport security training course came shortly after the 2019 course and during the COVID-19 pandemic in 2020 and 2021, a period that prohibited travel and personal contact. This was also the period during which the new Argonne training course on transport emergency response (NP-652) was developed and piloted virtually (in December 2021), the first time that an Argonne training course went paperless, and the time when the RFID key fob system for classroom interactions was replaced by *Slido*, a cloud-based audience survey system whose use was described in Reference [2], along with another cloud-based system, *Poll-Everywhere*, used in all other training courses conducted at Argonne during 2023. Both *Slido* and *Poll-Everywhere* are online audience survey systems that turn one-way slide presentations in the Argonne training courses into engaging conversations, with live polls or surveys that are designed to elicit anonymous student responses to questions. Because the course instructors got the aggregated feedback instantly, they were able to continue classroom discussion by exploring the reasons behind the differences in the student responses to the survey. This type of learning benefited everyone in the classes. Furthermore, the associated analytics and metrics provided summaries and objective measures of students' achievement of the learning objectives of the courses.

3. RECENT DEVELOPMENT/ENHANCEMENT

In addition to the interactive audience survey systems, several other advanced learning tools were developed by Argonne for the transport security and emergency response training courses over the years. Three web-based apps are described below for (1) automatic categorization of RAM and NM for shipment and generation of a TSP, (2) geofencing, and (3) extended-reality scenarios for transport security and emergency response exercises.

3.1. Web-based Nuclear Material Transportation Planning Tool (NM-TPT)

NM-TPT is a web-based app that automates the decision processes for categorization of RAM and NM, shown in Figures 2 and 3, respectively, and generation of a TSP with transport security provisions that meet all regulatory security requirements. These flow charts are complex and driven by applicable requirements and recommendations, with multiple decision points (Q1 to Q10) to complete categorization by applying all applicable security provisions. Twelve summary tables of International Transport security provisions for **RAMs**, four (RAM-1 to RAM-4) based on the United Nations Model Regulations (UNMR) and eight (RAM-5 to RAM-12) based on IAEA NSS-9, are provided at various decision points in Fig. 2, whereas fourteen summary tables—five (CPPNM-1 to CPPNM-5) based on CPPNM and Amendment, eight (NM-1 to NM-8) based on INFCIRC/225/Rev.5 (IAEA NSS-13), and one (NM-9) based on IAEA NSS-26-G—are provided for **NMs** at various decision points in Fig. 3. Each of these summary tables is followed by general and specific topics: for

example, RAM-1 provides **general security provisions** specified in the UNMR for most RAM transported by all modes; RAM-2 provides **additional specific security provisions** specified in UNMR for high-consequence RAM transported by all modes; RAM-3 provides **additional mode-specific security provisions** specified in the UNMR for most RAM transported by road, rail, and inland waterway; and RAM-4 provides **additional, subsidiary risks security provisions** specified in the UNMR for high-consequence RAM transported by all modes. Following the mandatory UNMR security provisions for RAM categorization alone is a challenging task, as is following recommended security provisions as set forth in IAEA NSS-9, Rev.1.

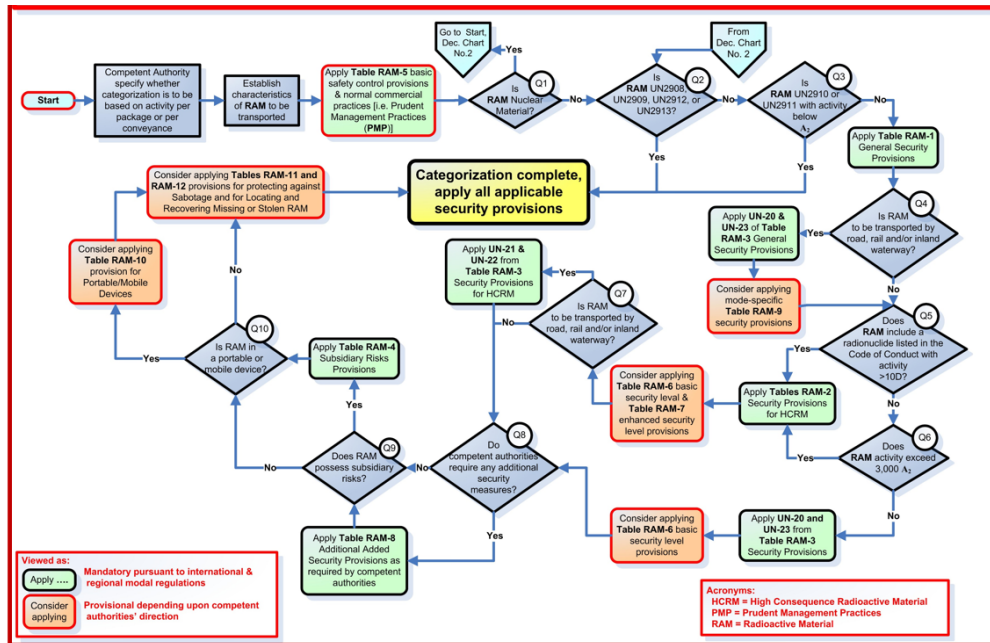


FIG. 2. Determination of Applicable Radioactive Material Categorization and International Transport Security Provisions Based on UN Model Regulations as Applied via IMO, ICAO, IATA, ADR, ADN & RID, and NSS-9 Rev. 1 Recommendations (15 March 2020)

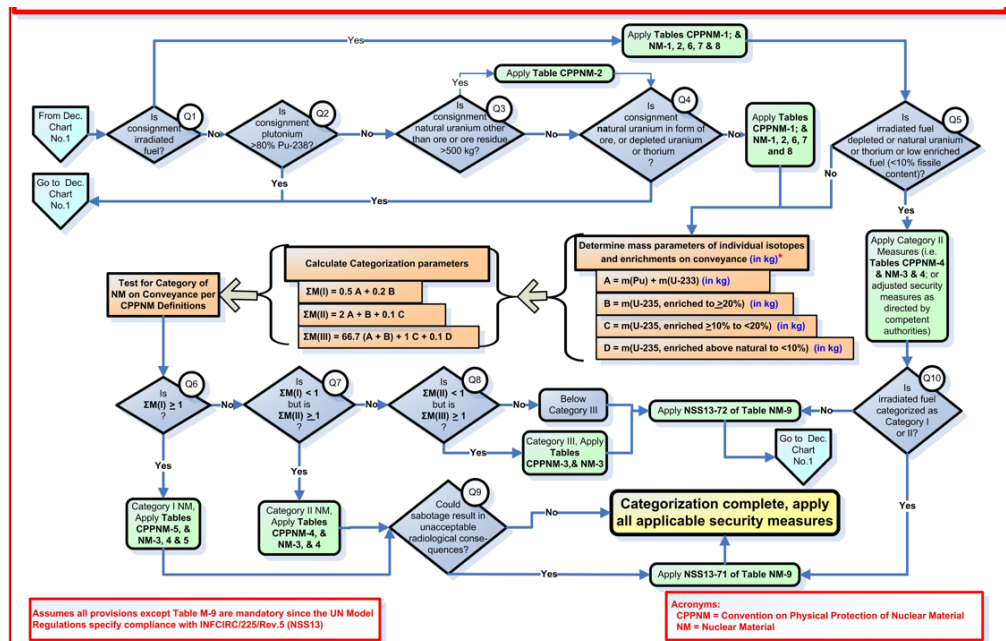


FIG. 3. Determination of Applicable nuclear material categorization and International Transport security provisions based on the CPPNM and its amendment, NSS-13, and 26-G Recommendations (6 May 2020).

Categorization of RAM and NM for shipment is necessary for the development of a TSP with transport security provisions satisfying various U.S. and international regulatory requirements for shipment. A typical TSP for NM and RAM shipment contains sections on scope, objectives, description of the shipment and material to be transported, administrative requirements, personnel qualifications, information management, transport security measures, and emergency response. Table 2 shows three major topics: 6. Information Management; 7. Operational Transport Security/Physical Protection Measures; and 8. Emergency Response, each with associated subtopics that are included in the TSP. The check boxes to the right of each TSP topic and subtopic show organizations (DOT, NRC, ICAO, IMO, IAEA) that give requirements or recommendations for RAM and NM. Notice that for NM, the IAEA INFCIRC recommends inclusion of all topics and subtopics in the TSP, whereas for both RAM and NM, all organizations except NRC require or recommend inclusion of the 7b subtopic **Operations Communications, Command and Control; Shipment Tracking** in the TSP. Together with the material categorizations for RAM and NM in Figs. 2 and 3, preparation of a TSP with Required/Recommended security provisions is almost akin to preparation of U.S. Federal, State and local income tax returns, in that a web-based app should greatly ease the burden, as would TurboTax when filing income tax returns.

TABLE 2. SUMMARY OF ORGANIZATIONS' REQUIREMENTS AND RECOMMENDATIONS FOR TOPICS TO BE INCLUDED IN THE TRANSPORTATION SECURITY PLAN (TSP) FOR SHIPMENT OF RAM AND NM

TSP Topic	RAM			NM	
	DOT	NRC	ICAO/IMO	NRC	INFCIRC/225
6. Information Management					
a. Information Security		X	X	X	X
b. Records Retention	X	X		X	X
c. Confidentiality		X	X	X	X
d. Protection of Information	X	X	X	X	X
7. Operational Transport Security / Physical Protection Measures					
a. Primary and Alternate Routes, Intermodal Transfers, Storage in Transit, Stopping Places	X	X	X	X	X
b. Description of Security System	X	X	X	X	X
o Equipment and Modes of Transport	X	X	X	X	X
o Operations Communications, Command and Control; Shipment Tracking	X	X	X		X
o Escort, Guards and Response Force Personnel	X	X	X	X	X
o Additional Security Measures	X	X	X	X	X
o Maintenance and Testing of Systems and Equipment	X	X	X	X	X
8. Emergency Response					
a. Non-tactical Emergency Response				X	X
b. Tactical Emergency Response				X	X
c. Incident Communication					X
d. Notification of Relevant Agencies					X

- **RAM:** Radioactive Material
- **NM:** Nuclear Material
- **DOT:** U.S. Department of Transportation
- **NRC:** U.S. Nuclear Regulatory Commission
- **ICAO:** International Civil Aviation Organization;
- **IMO:** International Maritime Organization
- **INFCIRC/225:** IAEA The Physical Protection of Nuclear Material

X: Required/Recommended

3.2. Web-Based Geofencing

A secured server-based geofence app has been developed for the ARG-US TRAVELER that enables establishment of virtual geographic boundaries for vehicle shipments of RAM [3, 4]. An established geofence, defined by the ARG-US TRAVELER's Global Positioning System via cellular or satellite communication, will trigger alarms automatically when a tracked vehicle *en route* with a shipment violates it, via either location or travel time. Advanced notification of shipment arrival and border crossing, and immediate notification to stakeholders when emergencies occur, are other key features enabled by the geofence app. The four basic building blocks in constructing a geofence for vehicle shipment are Zones, Legs, Route, and Trip. A Trip is arranged by stitching Zones together to form a Route, which provides an itinerary that specifies where a vehicle shipment should or should not be, relative to the amount of time that has passed since the start of the defined Route. Each Route must have one or more Legs. A Leg is a combination of single Zones, each of which is a geographic area of interest, and an activity window, which is the time period of interest. Each Leg is also marked as either Inclusive or Exclusive. An Inclusive Leg indicates that the vehicle is expected to traverse the given Zone during the activity window, whereas an Exclusive Leg indicates that the vehicle should not traverse the given Zone during the activity window. Like NM-TPT, a web-based ARG-US geofence zone formation tool

has been developed for training and used for the ARG-US TRAVELER in NM and RAM truck shipments in the U.S. since 2019. The web-based geofencing tool shows the steps for creating a buffer polygon across a desired route to be uploaded to the ARG-US secured server and used as an inclusive Leg. A companion video has been produced to help clarify the steps because without a visual aid, they can be difficult to follow in constructing a geofence for an NM or RAM shipment, as described in Reference [5].

3.3. Web-Based Extended-Reality Scenarios

Extended reality, including virtual reality and augmented reality, is increasingly used in nuclear training and education, including emergency preparedness and response. Argonne has developed a transport emergency response training course (NP-652) that employs web-based extended-reality scenarios in class exercises [6]. During the course, students are introduced to transportation accidents that require them to conduct incident scenes and packaging assessments requiring multiple skill sets. The instructor can rapidly cycle through training variables, including packaging damage, increased radiation levels, and other scene hazards (e.g., fire, damaged power lines, fuel leaks), thereby reducing the time needed to set up and conduct the evolutions, as well as minimizing students' ability to predict the scenario by observing training-aid setup. The instructor can fully test the range of postulated scenarios, including those with beyond-design-basis damage and radiation levels. An example of a recent scenario development was simulated radiation measurement using a mass attenuation coefficient transport model integrated with multiplayer voice and visual interactions in virtual reality on Oculus Quest 2. The multiplayer scenarios included real-time voice communications and simulated physical interaction in the synthetic environment (e.g., pointing at a hazard, such as a downed power line; showing a personal radiation detector display; and approaching the scene either together or from separate angles). The proof-of-concept scenes use Photon Unity Networking and Photon Voice. These web-based tools allow users of the app to connect to a web server and participate in the training scene remotely, with up to 10 simultaneous connections. The positions and states of users and grappable objects are synchronized across clients so that all users can see all other users and interact with the same objects in the scene. This approach allows students to train in realistic emergency scenarios that are either too hazardous for in-person training or not feasible for in-person training because of facility restrictions, while still maintaining realistic joint operations among students in multiple disciplines (e.g., radiation specialists and law enforcement). Details of this web-based extended-reality scenario training tool can be found in Reference [7].

Ongoing development of web-based apps for the transport security training courses at Argonne also includes blockchain for the ARG-US TRAVELER. Blockchains are often referred to as Distributed Ledger Technology because a blockchain is essentially a ledger of recorded transactions that is distributed or shared with multiple participants. These transactions include participants querying, reading, or writing data through a smart contract. The blockchain stores these transactions in records known as "blocks." Each block (except for the genesis, or first block) is linked to a previous block, creating a blockchain. Data in a block, once entered, cannot be changed; thus, blockchains are immutable. The majority of participants must reach consensus before a transaction takes place and is synchronized across the network. Blockchains are thus decentralized—there is no central authority in control, allowing full real-time access. The existing ARG-US TRAVELER system implementation relies on a centralized relational database to store all the information collected by the monitoring units. Seeking to improve the information security of the data collected by the ARG-US TRAVELER, Argonne researchers are developing a new blockchain prototype [8] that implements a distributed ledger system based on the Hyperledger Fabric platform, which is an enterprise-grade, distributed ledger platform that is modular and versatile. Unlike widely used public blockchains, such as Bitcoin and Ethereum, Hyperledger Fabric offers a scalable and secure platform that supports private transactions and confidential contracts. This architecture allows for solutions developed with Hyperledger Fabric to enable trust, transparency, and accountability. Testing and evaluation of the blockchain prototype for ARG-US TRAVELER is projected to start in the summer of 2024.

4. DISCUSSION AND FUTURE DIRECTIONS

Since the inception of the transport security training effort in 2013, the goal has been to improve the ability of the participants to prevent those with malicious intent from stealing, diverting, or attacking shipments

of NM and other RAM. The breadth of experience and knowledge developed through these training courses in the intervening years has been used to contribute significantly to two WINS Best Practice Guides focused on transport security [9, 10], a case study on electronic tracking [11], and the WINS Academy training module on Transport Security Management [12] in supporting capacity building [13] and next-generation security [14]. Significant enhancement can be expected in the future training courses on transport security, which will also incorporate the latest work by Argonne researchers on transport safety, security and safeguards of NM and other RAM [15] and culture analysis for international nuclear transport [16].

The International Conference on Nuclear Security: Shaping the Future, ICONS 2024, is the fourth ICONS following previous ICONS held in 2020, 2016 and 2013. According to the conference announcement, ICONS 2024 will inform preparation of IAEA's next Nuclear Security Plan, which will cover the period 2026–2029.

At the 65th IAEA General Conference in September 2021, the Director General presented the Nuclear Security Plan 2022–2025 [17], which included the following statements:

“Activities under this Plan may, where appropriate, assist States’ efforts to establish effective and sustainable national nuclear security regimes and, where appropriate, to fulfil their obligations including under the Convention on the Physical Protection of Nuclear Material (CPPNM) and its Amendment as well as the relevant United Nations Security Council Resolutions (UNSCRs), including UNSCR 1540 Agency assistance in capacity building and in facilitating information exchange and sharing of information, as appropriate, is provided solely at the request of States, and nothing in the Plan is intended to impose obligations upon States.”

In the Nuclear Security Plan 2022–2025, IAEA identified four projects, corresponding to four areas of expertise relevant to nuclear security of NM and other RAM and associated facilities and activities: (1) Integrated nuclear security approaches for the whole nuclear fuel cycle; (2) Enhancing security of NM and associated facilities; (3) Enhancing security of RAM and associated facilities; and (4) Nuclear security in transportation of NM and RAM. In addition to its use in classroom demos and field exercises in the transportation security and emergency response courses, the ARG-US remote monitoring systems have been used to support transport and facility operations at Argonne and elsewhere, as described in References [18–22]. Demand for training on ARG-US systems is expected to increase in the future as the technologies gain application in supporting field operations.

5. SUMMARY AND CONCLUSIONS

Since 2013, Argonne National Laboratory (Argonne) has conducted week-long training courses on transport security and emergency response for nuclear and other radioactive material. The goal of the transport security courses is to help participants gain a working knowledge and understanding of the United States and international requirements and recommendations for security during all modes of transport. COVID-19, while preventing travel to attend in-person training in classes, provided opportunities to explore electronic delivery platforms using advanced learning tools, including web-based apps for categorization of materials and transport security plans; geofencing and extended-reality scenarios for transport security and emergency response exercises; and interactive audience survey systems. These new tools should greatly enhance future training on security for packaging and transportation of nuclear and other radioactive material in nuclear fuel cycle operations.

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