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Nuclear Forensics and Development of Non-Destructive Scrutiny Facility (NDSF) for the Kingdom of Saudi Arabia

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Abstract: In this paper, theoretical model for nuclear forensics is developed and the Kingdom of Saudi Arabia (KSA) is considered as the case study. The main objective of this research is the development of procedure for nuclear forensics and infrastructure for non-destructive scrutiny facility (NDSF). In this study, various assumptions and parameters were discussed including the development strategies, technical evaluations, capabilities and current scenarios. The prime objective is to gain insight to the threat and unexpected issues regarding the race of nuclear technology in Middle East and North Africa (MENA) region and to safer the KSA region.

Keywords: Nuclear Forensics, NDSF Facility, Establishment Procedures, Techniques, Security Threat

1. Introduction

Nuclear forensics by its meaning denotes intercepted interact or retrieved information from some explosion debris. The characterization is simply the physical condition, age, history, implications of the nuclear devise design and so on. These results might be obtained from the sample analysis including laboratory and computer modeling and simulation studies with databases that contains empirical formula origination or from the results of numerical simulation of devices. In this scenario, manpower with specialty in receiving and to retrieve relevant data with strong recognition of the role and limitations of nuclear attribution is required.

In the history, radiochemistry techniques played a vital role in suggesting and to determine the characteristics of the material and their design specifications mostly practice in United States of America and some other countries as well. But the concerned for detonated and debris is still needed to be recovered by nuclear forensic techniques attributed to either intercepted materials or an actual explosion to its originators. This information emphasis on the new requirements of the technical analysis and availability of databases and libraries which includes samples from various countries which are more important than the case when the principal application was investigated diagnosis of explosion.

Nuclear smuggling received attention in early 1990(s) upon the breakdown of Soviet Union and the first case was registered in 1991 in Switzerland and later in Italy. Then subsequently, many other cases of illicit trafficking of nuclear materials were reported in Czech Republic, Germany, Hungary, and central Europe countries. With this backdrop, the major authorities took keen interest on the origin and intended use of these radioactive materials and thus, a new thought had been developed called "nuclear forensics". Analytical and classical approach had been developed including the data interpretation and computerized model development followed by establishment of nuclear smuggling international technical working group (ITWG) with collaboration between Russia and Germany. These approaches depends upon the measurement of certain parameters for the purpose to easily find out the origin and identification of the material [1].

The subsequent role of other nations on intercepting nuclear materials or debris from nuclear detonation can possibly be applicable to contribute the interpretation of radioactive materials. Keeping this scenario, an international global combat for nuclear terrorism has been launched and its proceeded meeting is taking place on yearly basis.

In June 16-17, 2015, Global initiative to combat nuclear terrorism (GICNT) held in Finland for its 9th level of plenary meeting aiming to tackle the emerging nuclear security challenges. Subsequently from 2015-2019, Russia and USA co-chairs GICNT meetings. However, some of the plenary meetings have already been taken place during the year 2013-2015 in different countries [2]. For instance, a workshop on nuclear forensics entitled Blue Beagle was held in London in 2013 and in subsequent workshop on cross-disciplinary training workshops entitled Tiger Reef held in Malaysia, while nuclear detection and training workshop held in Mexico in the same year. In 2015, four meetings on various topics of nuclear forensics took place in Hungary, Finland, Netherlands, Philippines and in Germany. In this paper, the aim is to establish nuclear forensic laboratory for the purpose to investigate nuclear probable threats concerning with trafficking and used of nuclear materials in general as well as in the KSA as special case.

2. Research Methodology

For development of threat scenario and establishment of nuclear forensics facility, two approaches were considered as shown in figure.1. Analytical and classical approaches which is further sub-categories leads to the origin of the sample [3]. At first, methodology for analyzing the origin of radioactive sample is discussed and then risk assessment involves in quantifying and evaluating the nuclear aspects of KSA on embarking nuclear power program. The uncertainty propagation factor for calculating the age of radioactive sample has been defined and evaluated [4]. This factor gives the age of the radioactive sample with time elapse along with particular radioactive nuclei that was chemically separated from its decay product.

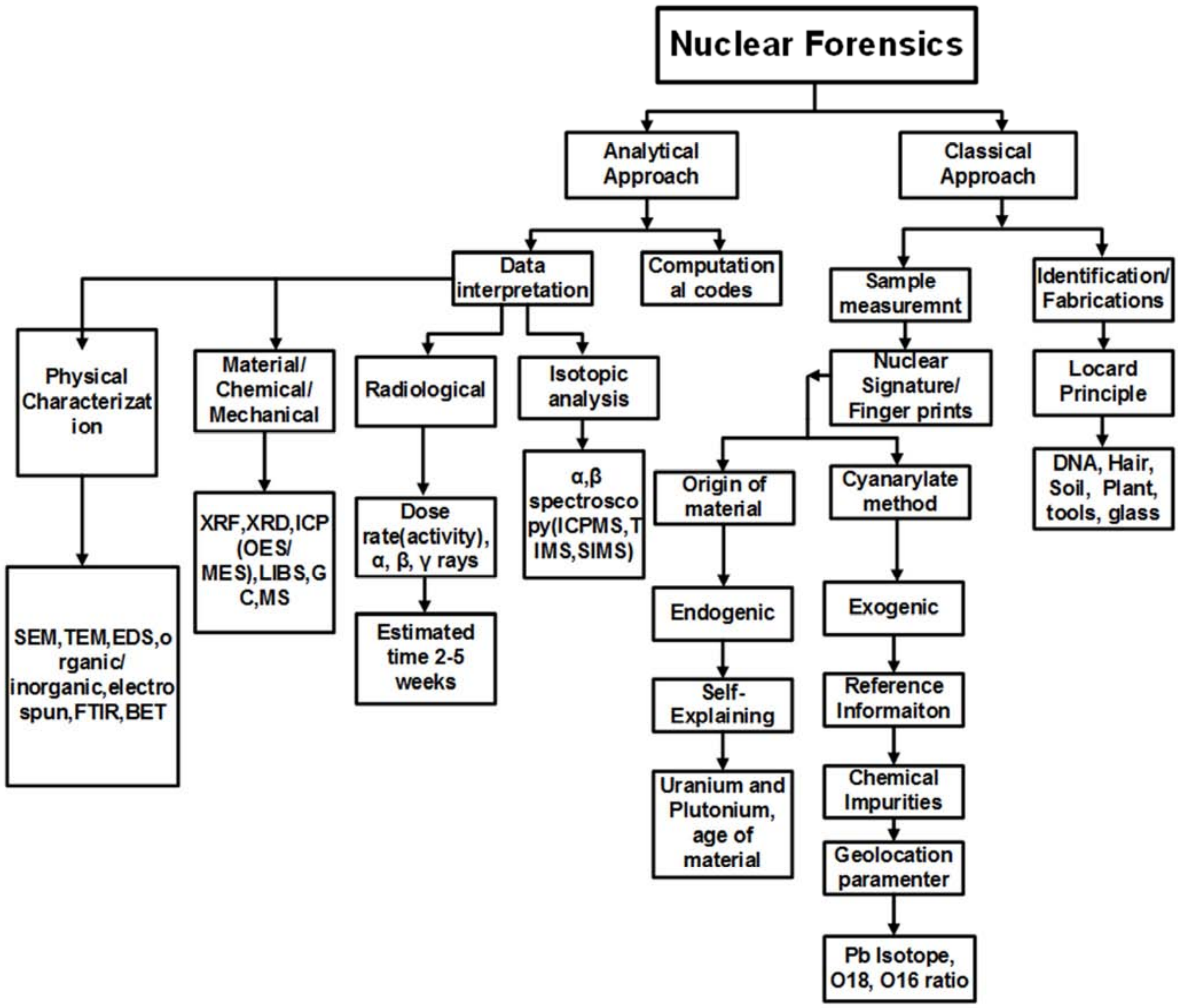

__Figure 1.__ Flow diagram of Nuclear Forensics Scenarios.

The decay process is governed by the mathematical formulation depicting the parent and daughter nuclei i.e.,

$$(Parent\ Nuclei)D_1 = D_1(0)e^{\lambda_1 t} \quad (1)$$

$$(Daughter\ Nuclei)D_2 = D_2(0)e^{\lambda_2 t}D_1(0)\frac{\lambda_1}{\lambda_2-\lambda_1} \quad (2)$$

Dividing equation (2) by equation (1) to get the age of nuclei,

$$\frac{D_2}{D_1} = \frac{D_2(0)e^{-(\lambda_2+\lambda_1)t}}{D_2(T)} + \frac{\lambda_1}{\lambda_2-\lambda_1}\left(1 - e^{-(\lambda_2+\lambda_1)t}\right)$$

This ratio gives the age of sample material provided the decay constant of the sample is known [5]. In this way, nuclear material found out in different places can be assessed and in nuclear power plant gives the age of fuel. In MENA region, the race of nuclear holding material may get in an alarming situations and proper check and balance should be taken. Nuclear trafficking including nuclear weapons are gaining higher attention in light of nuclear reactor buildup strategies by some MENA countries. With terrorist activities especially in Asian region, the risk in safety and security of nuclear technology is getting higher and the developing countries with aim of generating nuclear power need to take safety steps. For analyzing the radioactive sample, a flow diagram is presented in Figure 2. While following these steps, a sample can be traced and identify with its origination [6].

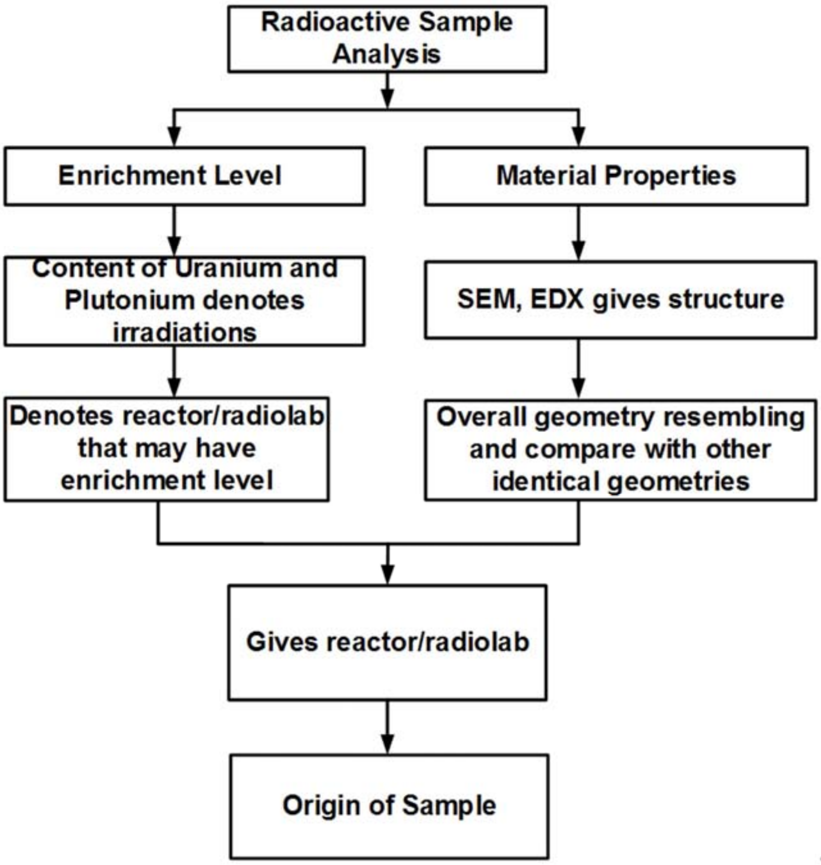

Figure 2. *Flow diagram of Sample analysis for Nuclear Forensics.*

3. Kingdom of Saudi Arabia in Nuclear Era

For the case of Saudi Arabia, it is estimated that the kingdom will have its own first nuclear power by the year 2022 and will be rich in nuclear energy by the year 2040 [7]. It was decided that the KSA will invest on the development of nuclear city and to collaborate with international community for providing the workforce and nuclear installation.

Saudi Arabia is located in a region with neighboring three countries have already started their nuclear program while rest of the countries are making strategies to opt nuclear power, among them Jordan has already established nuclear research reactor. Figure 3 illustrates a snapshot of KSA map with other countries. While trafficking nuclear materials within or from outside of the KSA, there could be a nuclear threat for this state. Therefore, safer and over protection missions need to be assigned for the safety of nuclear assets.

Figure 3. *Map of Saudi Arabia with neighboring countries (google map).*

The main areas of research and development includes the following.,

1. Signature
2. Equipment
3. Database
4. Manpower agreement
5. Nuclear device modeling
6. Debris collection

Advanced automated nuclear forensic equipment needs to develop for speeding up the collection and analysis process that would meet the desired timeline goals of the post-detonation nuclear forensics mission [8]. The need of deployable instrument providing the accurate sample analysis on shorter timescale arises as well. The collection of debris samples following the nuclear terrorist explosion is required in order to improve the capability to provide all possible scenario and responding capabilities. The best choice is to provide automated, portable instrument giving the accurate sample analysis of radiochemical and mass spectrometric studies of the samples [9]. This technique will give the authentication of the analytical information with confidence to government officials and decision makers. A simplified well defines nuclear forensics scenarios is presented in figure 4.

There is a need to developed databases and knowledge management system to support nuclear security (forensics) concerns. The database containing the information about uranium compounds including trace element concentrations, isotopic composition of uranium and other elements. Since, gathering and to consolidate all these information needs some computational tool as well as verified by foreign policies and governmental steps.

Archiving the samples gives all the information about the physical properties of nuclear materials and it is extremely helpful in gathering and knowing number of circumstances. In this scenario, the sample would have more information than already had.

The technique of reverse engineering can be applicable for transmuting the nuclear forensic data to update the modeling capability of the nuclear material and weapons. There are number of specialized nuclear reactor and safety codes that could ideally utilize for forensics application.

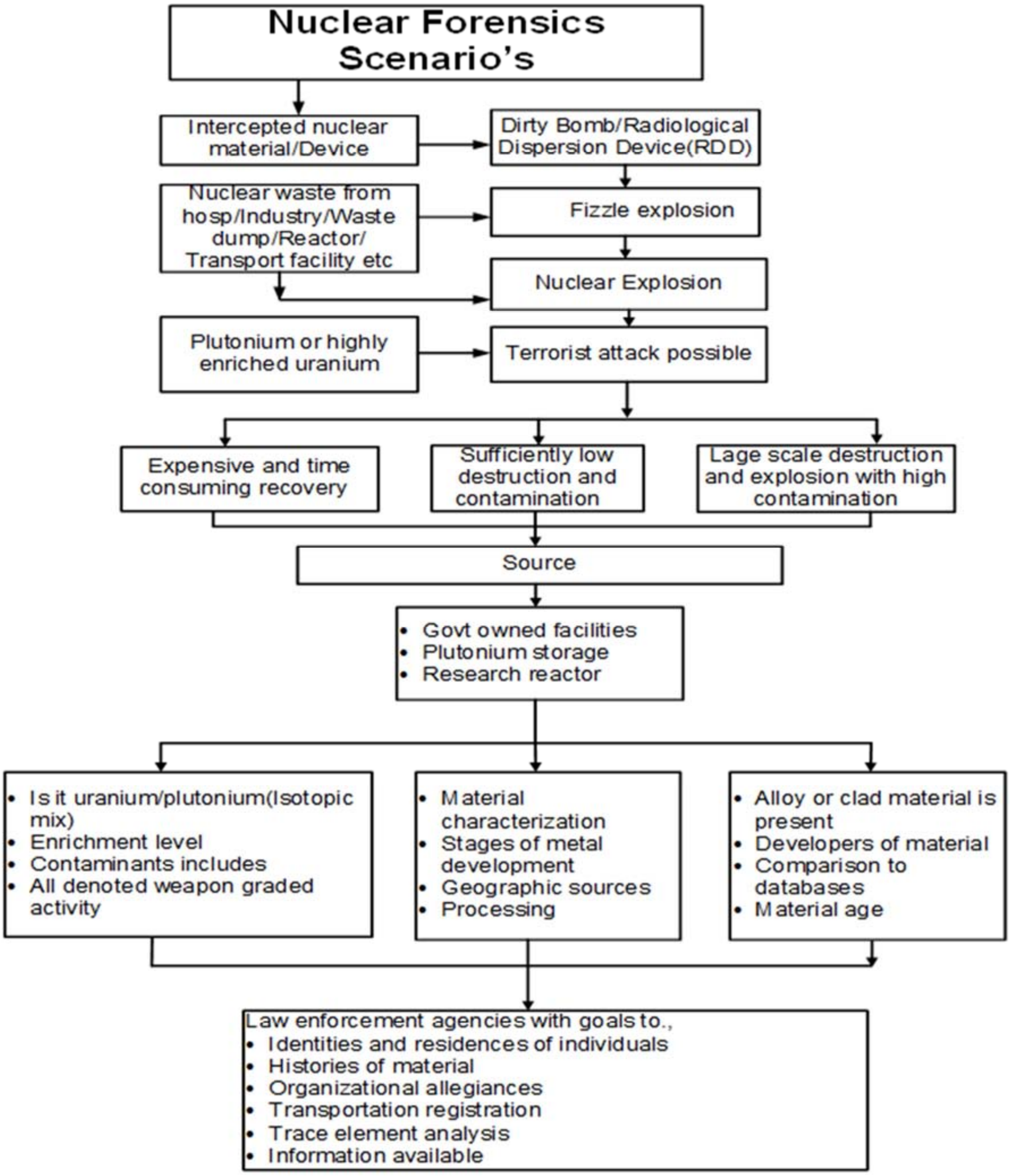

Figure 4. *Flow diagram of Nuclear Forensics Scenarios*

4. Establishment of Non-Destructive Scrutiny Facility (NDSF) for Nuclear Forensic

The establishment of nuclear forensic center requires involvement of high level Government officials and IAEA members. The main focus is to control the nuclear material for illicit trafficking and to overcome nuclear terrorism. Regarding the case of KSA with its ambition to produce nuclear power put question on the homeland security and safeguards issues [10]. In this scenario, there is a need to establish nondestructive scrutinize center for controlling and analyzing the nuclear material. There are few steps that should be consider while focusing on the development of this facility. These steps includes categorizing the seized nuclear material by law enforcement agencies, establishment of nuclear forensic laboratory for analytical and characterization techniques and screening procedure for categorization of materials. The output of the above mentioned procedures can be possibly forwarded to high level government officials and IAEA members [11].

5. Development Strategy

The schematic diagram of NDSF is presented in figure 5.

It was observed that the development of NDSF facility consisted of few steps. These steps includes (1) Initial characterization of material with jeopardizing conventional process, (2) Range of nuclear material by using analytical technique, (3) Physical and chemical state of material without any modification of original sample, (4) Nuclear security, safeguard, screening and categorizing, (5) Destructive analysis to be performed in analytical laboratories and to categorize nuclear materials, (6) The technique of destructive assay would be an important point to focus, (7) Destructive and non-destructive techniques and analysis are equally important.

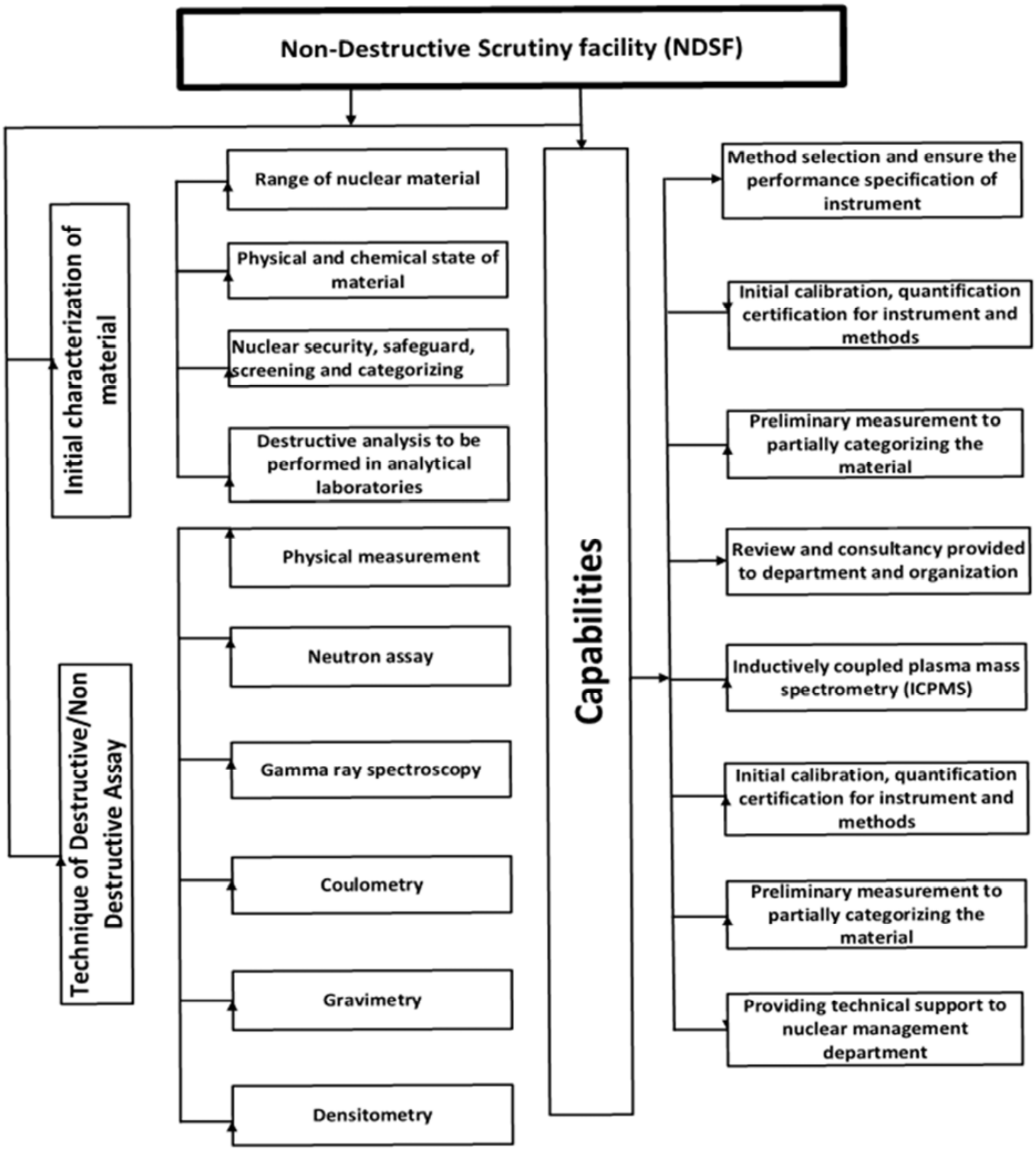

Figure 5. *Flow diagram of Non-Destructive Scrutiny facility (NDSF).*

6. Techniques for Analysis and Detection

Following are the techniques which are used for analysis and detection of nuclear materials,

1. Gamma ray spectroscopy

To determine the photon emission spectrum of radioactive materials and to identify the isotopes producing them [12].

2. Neutron assay

Undergoes fission detection of neutron U_{238} and Pu_{240}.

3. Physical measurement

By mass, weight, density and heat generated.

4. Coulometry

Utilizing Farady's law and electrolysis methods to find out the mass of sample, molecular mass and concentration within the sample.

5. Gravimetry

This is an analytical method used to do quantitative analysis by taking known volume of solution and by using a variety of techniques, removing or acquiring the dissolved analyte which can then be weighed [12].

6. Densitometry

It gives the relationship between the atomic number and the mode of electromagnetic interaction to infer the excitation and preferential emission of the targeted material [13].

7. Inductively coupled plasma mass spectrometry (ICPMS)

This is very powerful technique used to ionize the sample and find out the mass to charge ratio in which a detector can receives a signal proportional to the concentration within the sample [13]. Major options of adopting non-destructive scrutinizing technique includes traces of major elemental analysis as well as to determine the structure and morphology in case of interdicted nuclear material or radiological accident.

7. Capabilities of the NDSF Center

The NDSF center needs to have the capability for working on selection of methods and to ensure the up-to-the standard performance specification of instrument. Initial calibration, quantification certification for instrument and methods for nuclear forensics interpretation and reporting should be carefully examined. In addition, preliminary measurement should be taken for partial categorization of the material. The aim is to provide technical support to nuclear management department. Finally, review and consultancy should be adopted by the department and organization.

8. Current Scenario

For the case of KSA, some measure needs to be consider, such as filling up the gaps for the purpose to use available resources and existing collaboration, development of dedicated nuclear material accounting lab and to trained persons, facilities and equipment's.

9. Conclusion

The work contained in this paper includes history and research methodology for nuclear forensics application. The research is also extended to the development of NDSF facility in KSA as per the need of nuclear technology in the region. This NDSF facility will help to establish nuclear forensic laboratory mainly considered for safeguard and security reasons. It is estimated that the developed NDSF center will be able to create international database for the security of the state and over protection mission need to be assigned for this purpose. Well trained and highly skilled nuclear technological experts are needed to run this facility. At this stage, not only the KSA but also the countries that are at the pioneer stage of nuclear technology should work on these aspects of nuclear threat.

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