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Template identification technology of nuclear warheads and components*

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Template identification technology (TIT) is designed for the scenarios where a batch of disarmed nuclear weapons or components would be dismantled to observe a nuclear disarmament treaty. The core function played by the TIT is to make a judgment on whether the verified item belongs to a certain kind of nuclear weapons or component (NW/NC) or to which kind the verified item belongs. This paper analyses the functions played by the TIT in the process of NW/NC dismantlement, and proposes that two phases would be followed when applying the TIT: firstly to establish NW/NC templates with a sample of size n drawn from a certain kind of disarmament NW; secondly to authenticate NW/NC by means of the TIT. This paper also expatiates some terms related to the concept of the TIT and investigates on the development status of NW/NC TIT based on radiation signatures. The study concludes that the design of template structure is crucial to the establishment of an effective TIT and that starting from different research angles and aiming at the same goal of classification different template structures and corresponding template identification methods can be built up to meet specific identification requirements.

Keywords: nuclear warheads, nuclear components, template identification technology
PACC: 0150M，0650D

1. Introduction

Nuclear identification technology is one of the key verification technologies used in the context of deep-cut nuclear disarmament. Based on the studies conducted by some experts from the United States, Russia and Britain, an attribute approach and a template approach are proposed to authenticate nuclear warheads or nuclear components (NW/NC).[1−2] The attribute approach makes an integrating judgment on whether verified items are agreed with what a host party has declared by detecting some attributes of the NW/NC. The template approach makes a judgment on whether the verified items belong in a certain kind of NW/NC by means of template match. In recent years, we have focused on the research and development of a gamma-ray integrated measurement prototype of plutonium component attributes.[3] Meanwhile, we have carried some primary studies on the template approach.[4]

This paper conducted an investigation on the development status of template identification technology (TIT). The purpose of this investigation is to clear the functions played by the TIT in the process of NW/NC dismantlement, and the concepts and development status of this technology.

2. Application scenarios and functions of the TIT in the process of NW/NC dismantlement

Application scenarios[4,5] of the TIT in the process of NW/NC dismantlement are shown in Fig.1. Two phases are followed.

Phase 1: to establish NW/NC templates with a sample of size n drawn from a certain kind of disarmament nuclear warheads (NW). The host party would put the treaty-limited-items (TLI), namely the NW that would be dismantled to observe a disarmament treaty, into a storage depot, and provides the verification party a classification-sorted list of series numbers that were steel sealed on the surfaces of NW in the process of manufacture. Some inspectors would pay

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a visit to the storage depot to draw a random simple sample of size n from the population of a certain kind of NW according to the listed series numbers provided by the host party. The number of n would be determined by the size of the population and the degree of confidence. Some bilaterally agreed verification approaches such as size measurements, weighting and attributive measurements would be applied to authenticate the sample. The sample would then be measured one by one to provide data needed by the establishment of a NW template. The template must be stored in a safe way. The level of security of the template must be high enough to meet the requirements of the treaty parties, especially those of the host party. The sample is labelled before being transported to a dedicated dismantling facility with the custody of some inspectors. To meet the arrival of the sample, the inspection party undertake two tasks: one is to conduct an investigation inside the facility to search for clandestine items or portals; the other is to authenticate the sample at the entrance through a label identification technology (LIT) and the TIT. The sample might be dismantled with the absence of some inspectors inside the facility, and the dismantled nuclear components (NC) (uranium/plutonium) would be placed in some dedicated containers. To see the departure of the NC containers at the exit, some inspectors would measure the containers one by one to establish a NC template. Same as the NW template, the NC template would also been highly secured. The measured containers would then be labelled and transported to a dedicated NC storage depot where they would be safeguarded pending a further decision.

There might be several kinds of NW in the TLI. For each kind of NW the above process would be followed to establish its NW template and NC template. All of the NW templates and NC templates might be respectively collected to establish libraries of NW templates and NC templates. If there is only one kind of NW in the TLI, or if the verification regime is designed to verify the dismantlement of one kind of the NW by another, then for the sake of security, the templates might be applied in a separated way.

Phase 2: to authenticate NW/NC by means of the TIT. The dismantlement of TLI could be started after the establishment of NW/NC templates. The host party would be in charge of the transportation of TLI from the storage depot to the dismantling facility, and some inspectors would authenticate the items inputting and outputting the facility by the TIT to ensure the efficiency of the dismantling activities. The NC containers would then be transported to the NC storage depot where they would be safeguarded by waiting for subsequence dismantlement. Once a decision was made to further dismantle a certain kind of NC, the host party would transport the NC from the storage depot to a dedicated NC dismantling facility, and some inspectors would meet the arrival of the transported NC at the entrance of the facility to authenticate the items by the LIT and the TIT to ensure the efficiency of dismantling activities.

The TIT can also be used in a storage verification to ensure that the stored items are indeed the NW/NC compliant with the treaty instead of some counterfeit or empty containers with a clandestine NC conversion for other purposes.

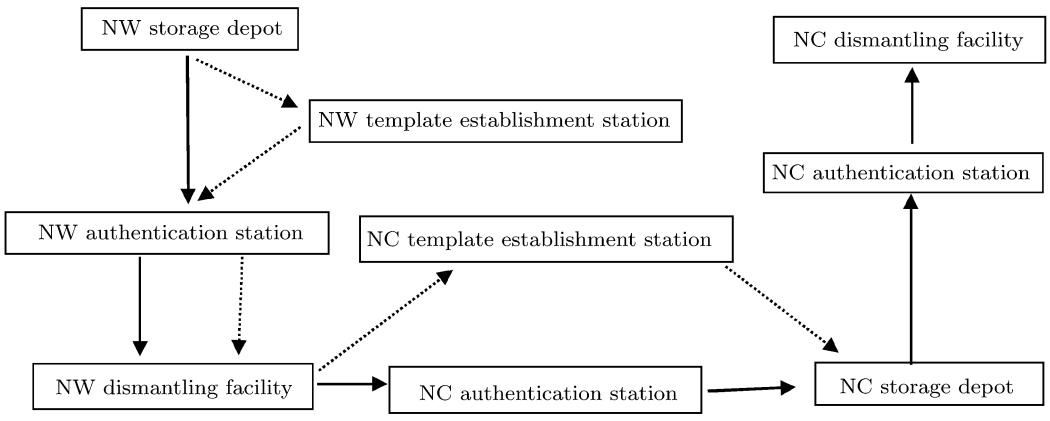


Fig.1. Application scenarios of the TIT in the process of NW/NC dismantlement. The dashed line shows the flow of templates establishment and the solid line shows the flow of templates application.

The functions played by the TIT can be summarized as follows:

a) confirm the warheads sent into the NW dismantling facility are indeed the NW of the certain kind;

b) confirm the components sent out of the NW dismantling facility are indeed the NC dismantled from the certain kind of NW;

c) confirm the components sent into the NC dismantling facility are indeed the NC dismantled from the certain kind of NW;

(d) confirm the stored NW/NC are indeed compliant with the treaty.

3. Concepts of the TIT

From the view of stockpile management, it might be necessary to authenticate batches or individuals of NW/NC. From the view of nuclear disarmament verification, however, the TIT is mainly used to authenticate the kinds instead of individuals of NW/NC, i.e. to make a judgment on whether the verified item belongs in a certain kind of NW/NC or on which kind the verified item belongs in. Therefore, the TIT can be defined as a process which starts from taking measurements on a verified item, then processes the data in a specific format, and ends with a stepwise comparison of the processed data with the templates (one or more than one) in the library to judge which kind the verified item belongs in. Figure 2 is the conceptual framework of the TIT.

To establish the templates of the certain kind of NW/NC, a simple sample of size n would be drawn from a population of trusted kind of NW/NC, and the sample would be measured one by one under the same conditions to produce data that would be used to establish the templates. The template is actually a set of parameters that can uniquely determine the kind of NW/NC. An independent variable in the template is called a template element.[6] A set of template elements is called a template structure. A set of parameters of template structure corresponds to the template of the certain kind of NW/NC.

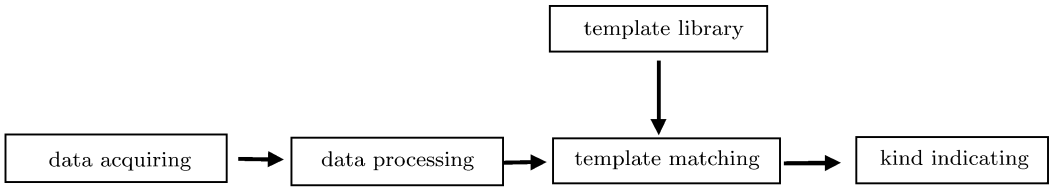


Fig.2. Conceptual framework of the TIT.

Values of template elements can be set with some direct data of measurement or with some characteristics (attributes) derived from the data of measurement. The data of measurement can be provided by a single or integrating measurement. The different values of a template element reflect the difference between different kinds of NW/NC in a certain degree. The selection of template elements is free of secrecy restrictions, namely, the template elements can be unclassified or secret or top-secret. If any secret template elements are involved, the corresponding template and the data of measurement (including the raw data and processed data) undoubtedly become secret and their security must be adequately ensured. From the view of security, it might be helpful for the verification party to certificate and keep a tough chain of custody of any inspection devices and template storage mediums (if the template storage mediums can be separated from the inspection devices).

In order to achieve a goal of classification the template structure should be designed in a careful and precise way so that it is able to reveal the difference between acceptable and unacceptable items of a verification regime. For instance, high resolution gamma-ray spectra are very complicated, in principle, a lot of valuable template elements could be designed from the spectra, however, in an extreme case where the difference between the verified items exists mainly in the low energy section of the spectra and the items are placed inside heavily shielded containers, a template structure designed with some template elements derived from the spectra would greatly devalue. There-

fore, to design the template structure high priorities should be given to the study of the necessity and sufficiency of template elements to clear the components of the template structure and the relationship between the components.

From the angle of study, different kinds of template structures for the same kind of NW/NC could be established, such as template structures based on radiation signatures (gamma & neutron) and non-radiation signatures (acoustic, electromagnetic and calorific). So far, the template structures based on radiation signatures have been widely and deeply investigated. In terms of measurements, the TIT based on radiation signatures can be subdivided as a TIT with gamma & neutron spectral measurements, a TIT with gamma & neutron intensity spatial distribution measurements, and a TIT with neutron coincident measurements.

Once the templates are established by the samples of different kinds of NW/NC, they can be used for identification. One thing needs to be emphasized is that the conditions of measurements for the verified items would be kept the same as those for the samples. If the template library has more-than-one templates, the conditions of measurements for the samples of different kinds of NW/NC would also be kept the same. If the conditions of measurements have some changes due to objective factors, an appropriate correction must be made when processing the data of measurement.

A template match is a process of comparison to judge whether a verified item is the same kind with the items from which a sample of size n is drawn to establish a specific template. The process of comparison is detailed as follows: firstly process the data of measurement in the format of template structure to form a set of parameters; secondly compare the set of parameters with the set of template parameters in a dedicate arithmetic to judge where the difference between the two sets of parameters are prominent in a certain level of confidence, in other words, to judge where the two sets of parameters can match each other in an acceptable tolerance. The comparison arithmetic and confidence level of the template match would be negotiated by the treaty parties. The negotiation would rely more on the technologies than some politic factors. The tolerance of the template comparison can be very strict because of the logic that if a template is unclassified, then the values of template elements would be unclassified and if a template is secret, then the template comparison could be conducted under protection of robust information barriers, so the values of template elements are hidden and nobody can know them.

The confidence gained from results of template measurements not only depends on the tolerance but also mainly on the authenticity and integrity of the templates. The template approach becomes nonsensical if the authenticity and integrity of the templates could not be absolutely guaranteed.

4. International development status of the TIT based on radiation signatures

4.1. TIT in the INF Treaty

The purpose of verification in the Intermediate-range Nuclear Forces Treaty was to distinguish the NW from non-nuclear warheads and multi-warheads from single-warheads. The template structure was designed as a two-dimensional matrix of neutron flux. The verification process was detailed as follows: first of all, place a missile on a dedicate platform; then locate some neutron counters in the positions of measurement which are shown by the grids drawn on the ground under the platform; finally measure the matrix of neutron flux and judge the legitimacy of the verified missile by template match. The data of measurement are unclassified, and the templates are shared.[7]

4.2. TIT with low-resolution gamma-ray spectral signatures

Sandia National Laboratories (SNL) has been working at a TIT with low-resolution gamma-ray spectral signatures. In 1994 a Radiation Measurement System (RMS) with a sodium iodide NaI detector was developed and put into application to authenticate plutonium components in containers at Pantex Plant. RMS has less consideration on the protection of sensitive information. In order to meet the requirements of nuclear disarmament verification technology on the protection of sensitive information SNL developed a Radiation Inspection System (RIS) on the basis of RMS and demonstrated RIS at Pantex Plant and Los Alamos National Laboratory respectively in 1997. RIS protects the sensitive information by means of software that shows a verification re-

sult on a computer screen in yes/no. Thereafter, SNL developed a Trusted Radiation Identification System (TRIS, Fig.3)[8] that protects the sensitive information by means of hardware. TRIS had succeeded in a series of trial identification including pits, warheads and Canned Subassembly.

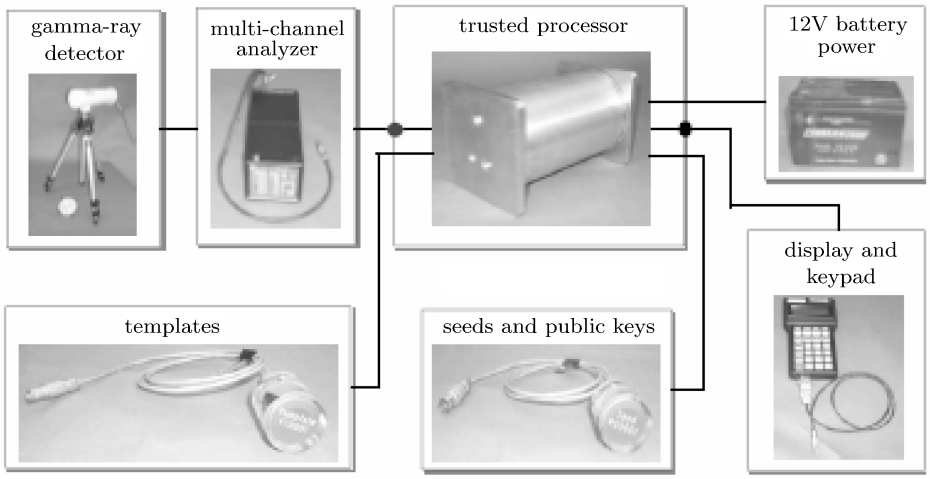


Fig.3. Subassemblies of the TRIS.

From RMS to RIS then to TRIS the development has focused on the information barrier technology to meet the requirements of nuclear disarmament verification technology on the protection of sensitive information. The three generations of the TIT are the same. The template structure consists of two arrays, one is for 17 ROI (range of interest) counts of a spectrum and the other is for their uncertainties. The method of template comparison is a Chi-squared χ^2 test.

4.3. TIT with high-resolution gamma-ray spectral signatures

Brookhaven National Laboratory (BNL) was the first to study a TIT with high-resolution gamma-ray spectral signatures. In 1988, BNL initiated a project to investigate a verification technology which takes use of intrusive high-resolution gamma-ray spectral measurements to reliably verify NW of potential disarmament treaties with preconditions of protecting some sensitive weapon design information from leakage. In 1994, a template identification system based on a high-resolution gamma-ray detector Controlled Intrusiveness Verification Technology (CIVET, Fig.4)[9] was built up. Since then, BNL demonstrated the CIVET for three times to the Department of Energy in years of 1994, 1997 and 1998 respectively to show the capabilities of protecting sensitive information and authenticating NW. Some Russian experts conducted an independent test and evaluation on the CIVET and concluded that the CIVET provided a valuable solution for non-intrusive measurements of sensitive items meanwhile pointed out some insufficiencies of the design, such as the defensive depth, reliability and confidence level. The CIVET was an early product and did not embody a perfect information barrier technology, but it did promote the shape and development of Information Barrier technology.

The template structure of the CIVET is an array of seven peak areas and their uncertainties. The involved peaks are 186keV of ^{235}U, 129, 375, 414, 451keV of ^{239}Pu, and 761, 1001keV of ^{238}U. The method of template comparison is ratios of peak areas.[10]



Fig.4. Prototype of the controlled intrusiveness verification technology.

4.4. TIT with coincident measurement signatures

Oak Range National Laboratory and Y-12 co-developed a Nuclear Weapon Identification System (NWIS) that was a TIT with coincident measurement signatures. From 1984, the NWIS was used to receive NC transported to Y-12 for storage. Based on a VAX computer the NWIS was cumbersome and needed intelligent judgments. In 1996 a miniaturized prototype of Nuclear Material Identification System (NMIS) was built up that could make automatic judgments of a verification task by means of template match and the identifications of NW/NC were demonstrated effectively. In recent ten years, the NMIS has been continuously improved with an integration of attribute approach with the template approach, and with a combination of passive measurements of plutonium components and active measurements of uranium components. The NMIS has been used for stockpile management in Y-12 Plant. Products of the NMIS have been exported to Russia.

Figure 5 is a typical measurement arrangement of the NMIS on a weapon assembly at Pantex Plant. On the right is a neutron source of ^{252}Cf ionization chamber, and on the left are four plastic scintillate detectors. The radiation of the ^{252}Cf source transits the weapon assembly or scatters by the weapon assembly or induces fissions in the weapon assembly. The three kinds of radiation arrive at the detectors. The signals of the detectors and the ^{252}Cf source are time sequences consisting of 0/1. The detection signal used for the template identification is a correlation function defined by formula (1):

$$C_{ij}(\tau) = \frac{1}{T-\tau} \sum_{t=0}^{T-1-\tau} x_i(t) x_j(t+\tau) \qquad (1)$$

where $x_i(t)$, $x_j(t)$ are respectively the signal of a detector and the signal of the ^{252}Cf source at time t; $C_{ij}(\tau)$ is the correlation function of the signals of a detector and the ^{252}Cf source at a delay time of τ; and T is a sampling period.



Fig.5. Typical measurement arrangement of the NMIS on a weapon assembly.

The correlation function is a curve of coincident count with decay time as shown in Fig.6. This curve is analogical with a neutron flight time spectrum that shows the radiations arrived at the detector in a sequence of transmitted gamma, transmitted neutrons, fast component of prompt decay, slow component of prompt decay and background.

The NMIS takes the correlation function as a whole signal that can reflect the spatial and temporal characteristics of the radiation field. The template structure of the NMIS consists of four correlation functions of the detectors and the ^{252}Cf source. The method of template comparison has been incessantly updated in order to enhance the identification capability of the system.[11]

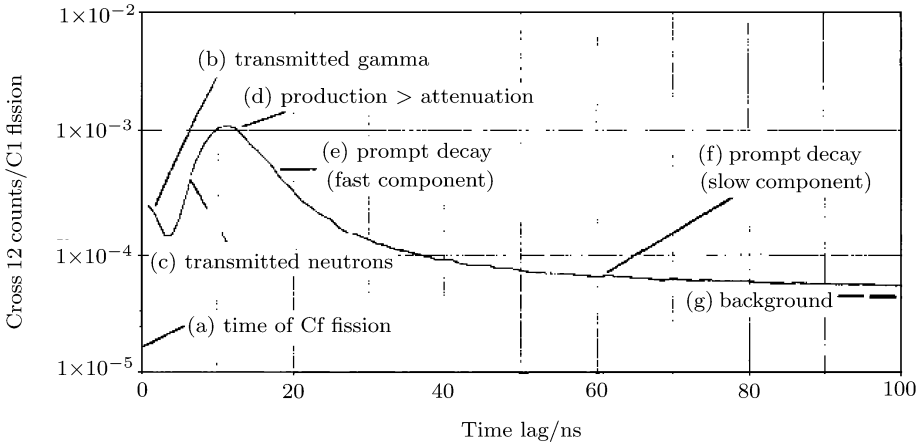


Fig.6. Detection signal used for the template identification.

5. Conclusion

The TIT is designed for the scenarios where a batch of disarmed NW/NC would be dismantled to observe a nuclear disarmament treaty. The larger the size of disarmed NW/NC is the more notable the advantages of the TIT are. The United States has taken a lead in the research and development of the TIT and has built up some prototypes or products to meet some specific requirements, however, these prototypes or products are still weak in terms of the tasks they are supposed to do in a context of nuclear disarmament. Starting from the application scenarios of the TIT, this paper analyses the functions played by the TIT, the concepts of the TIT and the development status of the TIT based on radiation signatures. The study shows that it is very important to design an appropriate template structure in order to meet specific verification requirements, in other words, the design of template structure is crucial to the establishment of an effective TIT. The study also points out that starting from different research angles and aiming at the same goal of classification different template structures and corresponding template identification methods can be built up to meet specific identification requirements. These conclusions would function as a foundation of a further research and development of the TIT.

References

[1] Office of Nonproliferation Research and Engineering 2001 *Technology R&D for Arms Control* (Washington, DC: U.S. Department of Energy)

[2] Comley C, Comley M and Eggins P 2000 *Confidence, Security and Verification: The Challenge of Global Nuclear Weapons Arms Control* (Aldermaston: Atomic Weapons Establishment)

[3] Liu S P, Hao F H, Gong J, Wu H L and Kang W 2007 *Acta Phys. Sin.* **56** 4406 (in Chinese)

[4] Liu S P, Gong J and Wu H L 2002 *Acta Phys. Sin.* **51** 2411 (in Chinese)

[5] Liu S P 2000 *A Verification Regime for Warheads Control* (Stanford University: CISAC)

[6] Kane W R, Lemley J R, Vanier P E and Zuhoski P B 2002 *On Attributes and Templates for Identification of Nuclear Weapons in Arms Control* (New York: Brookhaven National Laboratory)

[7] Lemley J R and Vanier P E 2000 *Proceedings of the 41st INMM Annual Meeting* (Illinois: Institute of Nuclear Material Management)

[8] Kevin D S, Dean J M and Thomas W L 2001 *Proceedings of the 42nd INMM Annual Meeting* (Northbrook, IL: Institute of Nuclear Material Management)

[9] Peter E V, Peter Z, Leon F and Andrey S 2001 *Proceedings of the 42nd INMM Annual Meeting* (Northbrook, IL: Institute of Nuclear Material Management)

[10] Walter R K, James R L and Leon F 1997 *The Application of High-Resolution Gamma-Ray Spectrometry (HRGS) To Nuclear Safeguards, Nonproliferation and Arms Control Activities* (New York: Brookhaven National Laboratory)

[11] Mihalczo J T, Valemine T E, Mullens J A and Mattingly J K 1991 *Physical and Mathematical Description of Nuclear Weapons Identification System (NWIS) Signatures* (Oak Ridge: Y-12 Plant)