The potential of open source information in supporting Acquisition Pathway Analysis to design IAEA State Level Approaches

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Abstract. International Atomic Energy Agency (IAEA) safeguards designed to deter nuclear proliferation are constantly evolving to respond to new challenges. Within its State Level Concept, the IAEA envisions an objective-based and information-driven approach for designing and implementing State Level Approaches (SLAs), using all available measures to improve the effectiveness and efficiency of safeguards. The main objectives of a SLA are a) to detect undeclared nuclear material or activities in the State, b) to detect undeclared production or processing of nuclear materials in declared facilities or locations outside facilities (LOFs), c) to detect diversion of declared nuclear material in declared facilities or LOFs. Under the SLA, States will be differentiated based upon objective State-Specific Factors that influence the design, planning, conduct and evaluation of safeguards activities. Proposed categories of factors include both technical and legal aspects, spanning from the deployed fuel cycle and the related state's technical capability to the type of safeguards agreements in force and the IAEA experience in implementing safeguards in that state. To design a SLA, the IAEA foresees the use of Acquisition Path Analysis (APA) to identify the plausible routes for acquiring weapons-usable material and to assess their safeguards significance. In order to achieve this goal, APA will have to identify possible acquisition paths, characterize them and eventually prioritise them. This paper will provide an overview of how the use of open source information (here loosely defined as any type of non-classified or proprietary information and including, but not limited to, media sources, government and non-governmental reports and analyses, commercial data, satellite imagery, scientific/technical literature, trade data) can support this activity in selected aspects of a typical APA approach.

1. The Context

1.1. Acquisition Path Analysis within the IAEA State Level Concept

The IAEA's State-Level Concept (SLC) is a holistic approach to nuclear safeguards considering the State as a whole greater than the mere sum of its nuclear-related installations. According to guidance issued by the IAEA, it "*applies to all States and involves a comprehensive State evaluation and State-level safeguards approach, including the identification of specific safeguards measures for each State, implemented through an annual implementation plan.*"[1]

The State Level Approach (SLA) for safeguards implementation is defined by the IAEA Safeguards Glossary as "*a safeguards approach […] developed for a specific State, encompassing all nuclear material, nuclear installations and nuclear fuel cycle related activities in that State. A State level safeguards approach defines the application of safeguards measures at each facility and location outside facilities in the State and, where an additional protocol is in force, the safeguards measures […] that would enable the IAEA to draw and maintain a conclusion of the absence of undeclared nuclear material and activities in that State*".[2]

The SLA is designed to achieve the following state-level safeguards objectives: [3]

A. Detection of any undeclared nuclear materials and activities
B. Detection of any misuse of declared facilities for undeclared nuclear material production or processing
C. Detection of any diversion of declared nuclear material

Objective A deals with undeclared activities in undeclared sites, i.e. completely clandestine activities. Objective B deals with undeclared activities in declared facilities, i.e. usually referred to as misuse. Objective C deals with diversion of declared nuclear material from declared facilities. Objective B and C are usually covered by traditional safeguards inspections. Objective A is usually much more complicated to cover and, according to the IAEA, cannot be properly addressed without an Additional Protocol in force.

In the State Level Approach, the IAEA makes use of Acquisition Path Analysis (APA).[3] The APA is defined as "*the analysis of all plausible acquisition paths or acquisition strategies for a State to acquire nuclear material usable for the manufacture of a nuclear explosive device*."[2] Acquisition paths are considered to be technically plausible if the State could, "*from a technical point of view, acquire at least one significant quantity of weapons-usable material* ***within five years***". All technically plausible acquisition paths will have to be covered in the State-Level Approach.[4]

The identification of plausible acquisition paths is supported by the IAEA's Physical Model, a collection of documents where a comprehensive set of technological acquisition paths are discussed in terms of the technologies and materials involved and the indicators of their presence within a State. These indicators can either be ***strong*** (presence of an indicator is necessary and sufficient for the existence of a given safeguards-relevant activity), ***medium*** (presence of an indicator is necessary but not sufficient for the existence of a given safeguards-relevant activity) or ***weak*** (presence of an indicator may be connected to the presence of a given safeguards-relevant activity but is neither necessary nor sufficient to determine its existence).[5]

Acquisition paths are characterized in terms of the ease and speed by which a State could acquire one significant quantity of nuclear material.[4] These factors will influence the type, intensity and frequency of safeguards measures in the design of a state-level safeguards approach for a particular State.

1.2. Open source information and NPT compliance analysis

Within a systems approach, open source analysis could be described as "*getting the right information (what) to the right people (who) at the right time (when) for the right purpose (why) in the right forum (where) and in the right way (how)*" [6] by merging openly available data and information coming from a wide variety of accessible sources into a cohesive picture. It often requires the collection, filtering and handling of a large amount of data, a small fraction of which is really useful. It is therefore a situation in which the two problems of too much (mostly irrelevant) data and too few (useful) data coexist.

Although there is no universally codified definition of open source information, the U.S. Intelligence community defined it as "*publicly available information that anyone can lawfully obtain by request, purchase, or observation*".[7] The IAEA considers the term "open source information" to include – but not limited to – "*information generally available from external sources, such as scientific literature, official information, information issued by public organizations, commercial companies and the news media, and commercial satellite imagery*".[8] There are several discussions on open sources to be considered in a non-proliferation framework.[9], [10] While sources of open source information are too numerous to discuss in detail (e.g. social media, news media, journals, virtual globes, etc.)[11], there are four principal open source analytical areas that can support the APA:

- Technical/official information analysis: scientific literature, official information, information issued by public organizations, commercial companies [12]
- Media monitoring: news, blogs, social networks [13], [14]
- Imagery analysis: commercial satellite imagery, ground-level imagery [15]
- Import/export analysis: trade data [16], [17], [18], [19], legal/illicit procurement information

While the IAEA makes use of all information at its disposal (including *inter alia*, official declarations by the State, information collected during safeguards verification activities, third-party information, and open source information) [8], [20], this discussion focuses on the contribution of open source and the informational and analytical uncertainties involved when supporting the APA. As discussed below, these sources support the APA to varying degrees when monitoring suspect sites, verifying design information, assessing technical capabilities, and searching for indications of undeclared activities and imports.

2. Open source analysis in support of Acquisition Path Analysis

The stages of an APA identified by the IAEA are: [4]

1. "*Consolidating information about a State's past, present, and planned nuclear fuel cycle-related capabilities and infrastructure*
2. *Identifying and visually presenting technically plausible acquisition paths*
3. *Assessing a State's technical capabilities and possible actions to conduct each step of the technically plausible paths*
4. *Assessing the time needed to complete a technically plausible acquisition path*"

In the following paragraphs, the potential contributions of open source analysis to the four stages of the APA are described, along with potential informational and analytical uncertainties.

2.1. Consolidating information about a State's past, present, and planned nuclear fuel cycle-related capabilities and infrastructure

The first stage of the APA process collects and consolidates information on a state's past, present, and planned nuclear fuel cycle capabilities and infrastructure.[4] When evaluating a state's capabilities, specific analytical questions are posed according to the type of pathway (e.g. types and locations of materials for a diversion scenario). This information is then utilized when estimating the time required for a state to complete the path. Table 1 maps the possible use of open source analysis when evaluating a state's past, present, and planned nuclear fuel cycle capabilities and infrastructure. The first two columns list the areas of information needed to "prepare for conducting in-depth acquisition path analysis",[4] the third column indicates the potential role of open source analysis, and the remaining columns indicate where open sources can contribute.

Table 1.Potential roles for open source analyses in supporting the consolidation of information about a State's past, present, and planned nuclear fuel cycle-related capabilities and infrastructure.

Information Collection Areas [4]		**Potential Role of Open Source Analysis**	**Technical/ Official Information Analysis**	**Media Monitoring**	**Imagery Analysis**	**Import/ Export Analysis**
Present nuclear fuel cycle	Declared facilities, LOFs, and sites	CSA-only: Corroboration of state declarations (facilities, LOFs) CSA+AP: Corroboration of state declarations (sites)	Y	Y	Y	-
	Exports and imports of nuclear material	Corroboration of state declarations	Y	Y	-	Y
	Nuclear fuel cycle related R&D	CSA-only: main source of information CSA+AP: corroboration of state declarations	Y	Y	-	Y
	Exports and imports of equipment and non-nuclear material	CSA-only: main source of information CSA+AP: corroboration of state declarations	Y	Y	-	Y
	Uranium mines and concentration plants	CSA-only: main source of information CSA+AP: corroboration of state declarations	Y	Y	Y	Y
	Pre-34(c) material holders	CSA-only: main source of information CSA+AP: corroboration of state declarations	Y	Y	-	Y
Past nuclear fuel cycle activities		Corroboration of initial declaration	Y	Y	Y	Y
Planned nuclear fuel cycle activities		Indications of plans to acquire capabilities	Y	Y	Y	Y
Identified anomalies		Indication and investigation of anomalies	Y	Y	Y	Y

2.2. Identification of technically plausible acquisition paths

As defined by the IAEA, a path is considered technically plausible if the State could, "*from a technical point of view, acquire at least one significant quantity of weapons-usable material within five years*".[4] Therefore, technical plausibility is a matter of knowing what is technologically feasible, the identification of a state's strategies (e.g. indigenous production, diversion, misuse, clandestine, import), and a preliminary assessment of the time necessary to complete the path based on the intrinsic difficulty of the path and the state's capabilities to complete the path.

Open source plays a limited role in identifying technically feasible pathways, but are utilized when assessing technically plausibility. Feasibility and plausibility differ in that feasibility reflects technological possibilities (i.e. the production possibility set [21]) irrespective of a state's capability to pursue the path. The process of identifying feasible path steps begins with declared facilities followed by the addition of processes that are necessary to complete an acquisition pathway. There are five types of path steps by which nuclear material could be obtained [4]:

- **Indigenous production** of pre-34(c) nuclear material (nuclear material containing uranium or thorium that has not reached the composition or purity suitable for fuel fabrication or for being isotopically enriched)
- **Diversion** of declared nuclear material in declared facilities or locations outside facilities (LOFs), including nuclear material in transit (shipment/receipts)
- Undeclared production or processing of nuclear material in declared facilities or LOFs (i.e. **misuse**)
- Undeclared production or processing of nuclear material in undeclared facilities (i.e. **clandestine**)
- Undeclared import of nuclear material (i.e. **import**)

The process of feasible path identification appears to be well developed, leveraging a State's declarations and the IAEA's Physical Model [5] to identify technically feasible pathways for the production of nuclear material usable in a nuclear explosive.

Open source analyses play a role when evaluating the plausibility of a path step. A path is considered technically plausible if its use by a state within a defined set of time cannot be excluded. Therefore, technical plausibility is a preliminary assessment of the time necessary to complete the path based on the intrinsic difficulty of the path and the state's capabilities to complete the path. At this stage of the APA, technical plausibility acts as a screening criterion to limit the scope of analysis, excluding options judged to be too far off into the future to warrant further analysis. As technical plausibility is a question of path completion time, the role of open source in assessing intrinsic difficulty and capability to support estimates of time is discussed in the following sections.

2.3. Technical capability to accomplish each path step and the identification of State actions

Assessments of the technical capability of the state draw upon specific types of information from the consolidated information about a state. Relevant technical details of a state's capabilities depend on the type of acquisition path (indigenous production, diversion, misuse, clandestine, import). As discussed in this section, the role of open sources (summarized in Table 2) and the associated informational uncertainties vary amongst these five types of path steps.

Table 2. Illustrative roles of open source information and analysis in support of acquisition path steps assessment.

Acquisition Path Step Type [4]	Technical/Official Information Analysis	Media Monitoring	Imagery Analysis	Import/Export Analysis
Indigenous production of pre-34(c)	U/Th deposits, production activities/ capabilities	Current and planned activities	Monitoring of sites	Import/export of material and equipment
Diversion of declared nuclear material in declared facilities or locations outside facilities (LOFs), including nuclear material in transit (shipment/receipts)	-	Third-party information*	-	-

Acquisition Path Step Type [4]	Technical/Official Information Analysis	Media Monitoring	Imagery Analysis	Import/Export Analysis
Undeclared production or processing of nuclear material in declared facilities or LOFs	Technical capability to modify facilities and handle material	Third-party information*	-	Import/export of material and equipment
Undeclared production or processing of nuclear material in undeclared facilities	Knowledge and infrastructure	Third-party information*	Investigation of possible sites	Import/export of material and equipment
Undeclared import of nuclear material	Indications of import	Third-party information*	-	Import/export of material and equipment

* Examples of third party information include national intelligence agencies, non-governmental organizations, dissident groups, whistle-blowers, etc.

Assessing the **indigenous production of pre-34(c) material** requires characterizing actual and potential uranium and thorium deposits (location, operational status, size, grade, etc.) and the capability of the state to extract those resources. For states party to the Additional Protocol, declared sources and capabilities are well described in state declarations and open sources of information could be used to corroborate those declarations. For states not party to the Additional Protocol, literature on indigenous production activities and capabilities (such as the OECD "Redbook"[22]) could be utilized to characterize the resource base and potential ore locations. Additional information may be in the grey literature or proprietary in the case of the exploration activities of private companies. Commercial satellite imagery could systematically monitor these locations for signs of indigenous production and trade data could be collected to identify imports of material and equipment.

In the case of **diversion**, open sources are unlikely to play a leading role as verified stated declarations are by far the most valuable source of information. Relevant technical information on material quantities and properties, and the design of facilities are available to the agency for the purposes of developing a safeguards approach. Information related to a state's capabilities to divert material are relatively unimportant as managing the time, distance, and shielding issues associated with moving material are well within reach of most states involved in nuclear activities and are often legitimately pursued for the safe operation of a facility. Nevertheless, open sources may be useful in corroborating state declarations and planning safeguards activities (e.g. verification of site layouts via satellite imagery).

Similarly, **misuse** of declared facilities will largely rely upon verified state declarations of materials and facilities for assessing the time and effort required for producing or processing undeclared materials using declared facilities. Open sources can be useful for evaluating a state's capability to make process modifications or handle certain types of material should the misuse scenario require such capabilities. Such information could be obtained from known declared capabilities (e.g. the State is a technology owner in that nuclear process or a technology user) and from reviews of technical literature. The availability and reliability of information on a State's capabilities, however, is diminished if states control publication or rely upon well documented processes implemented by industrial personnel with little incentive to publish openly.[23]

In the case of **undeclared activities (including import)**, analysts require information on the knowledge and infrastructure available to a state to pursue clandestine activities. Open sources play a greater role when evaluating the potential for clandestine path steps and clandestine imports of material and equipment, but may be the least reliable. Evaluations of technical/official literature and trade could reveal information on the knowledge and R&D activities of state, a state's equipment manufacturing or purchasing activities, the availability of equipment within the state, and experience with operating related processes. Imagery could also monitor locations where clandestine activities are suspected. However, some facilities such as a "quick and dirty" reprocessing facility or a small enrichment plant may be very difficult to observe, particularly before they are operational.[24], [25], [26] Moreover, information may be incomplete, unreliable, ambiguous, and even deceptive, particularly if the State denies/suppresses signatures and/or engages in deception. Table 3 presents denial and deception methods that can contribute to informational uncertainties about a state's capabilities.

Table 3. Denial and deception methods contribute to informational uncertainties. Table adapted from chemical and biological weapon program signatures and concealment actions. [23]

Open Source Detection Methods	**Signatures Sought**	**Denial and Deception Methods**
Technical/ official information analysis & media monitoring	Research and development activities	Manage publication activities Use widely available technical information Alternative or modified processes Claim legitimate applications Cover stories
	Effluents (e.g. environmental monitoring, public health records)	Suppress effluents Suppress reporting
Imagery analysis	Security features	Conceal or place within other secure facilities
	Functional and operational design features	Mask true use through signature suppression
Import/ Export analysis	Patterns of material acquisition Special equipment acquisition Imports of dual-use equipment	Shuffle, divert acquisitions Obtain from multiple suppliers/intermediaries Mix with legitimate uses Develop clandestine networks Produce indigenously Divert equipment from legitimate activities Alternative processes Claim legitimate uses

2.4. Open source in support of the assessment of the path completion time

Estimating the time needed to complete an acquisition path is the most analytically challenging aspect of the APA process. Estimating the time necessary for a state to complete a pathway involves comparing the intrinsic difficulty of the path steps to the capability of the state to carry out the path step. To draw an analogy, much as the apparent ease and grace of a professional ballerina belies the difficulty of ballet, the concepts of ease and speed reflect a combination of the intrinsic difficulty of the task and the capabilities of the performer. Therefore, pathway completion time is a relative measure – what is easy and fast for some may be difficult and slow for others. Estimating how fast or how slow, however, must contend with sources of analytical uncertainty in estimates of intrinsic difficulty and time.

Though much of the necessary information has been collected by this stage, open source can play an additional role when evaluating intrinsic difficulty by making use of existing evaluations. For example, several studies have reported on the infrastructure requirements for a clandestine reprocessing facility.[25], [26] Another study catalogued timelines for nuclear fuel cycle technology research and development efforts by States.[27] Caution is necessary when evaluating these studies as qualitative statements can be misleading. For example, some studies state that "… all enrichment techniques demand sophisticated technology in large and expensive facilities", suggesting that enrichment is out of reach of all but the most capable states. In contrast, other studies suggest that "… it [is] feasible for countries with no prior experience, 'that possess relatively little technical skills and which have relatively little industrial activity,' to produce enriched uranium for nuclear weapons by means of a small centrifuge plant."[28]

Once a task has been defined in sufficient detail, engineering management methods could be used to estimate the time necessary to complete a task in light of a state's capabilities and resources. As noted by the developers of the Program Evaluation Research Task process for project management, "The status of a developmental program at any given time is a function of several variables: resources, in the form of dollars, or what 'dollars' represent-manpower, materials, and methods of production, technical performance of systems, subsystems, and components, and time."[29] These types of engineering assessments can serve as a means allocating safeguards resources by identifying processes whose disruption would delay progress towards weapons-usable nuclear material.[30]

The certainty to which engineering assessments can estimate ease and speed varies with the type of pathway under consideration. Even assuming certain input data, the certainty of the output depends in part upon the degree to which factors of production are fixed or variable in an assessment. In the parlance of production economics, factors of production (e.g. land, labor, capital equipment) are fixed and not readily altered over the short-run. In the long-run, all factors of production are variable.[31]

Assessments of **diversion** and **misuse** path steps are more certain as factors of production are largely fixed. In the case of diversion, assessments of diversion path steps will mainly rely on State declarations. The need to understand a state's technical capability to divert material is relatively limited to whether or not a State has the capability to manage the time, distance, and shielding issues of moving material and perhaps understanding safeguards methodologies if detection is a concern – but these capabilities are well within reach of virtually all states involved with nuclear technology.

Misuse path steps are somewhat more complicated than diversion as factors of production are more variable and a state's capabilities are more salient, leading to greater analytical uncertainties. Though there are more variable factors, including the possible use of **indigenously produced** or **imported** feed material, existing facilities impose constraints on modifications that are implementable in the short-run e.g. using excess capacity or modifying existing equipment. Understanding a state's technical capabilities are of greater relevance than in the case of diversion as not all states may not be as equally capable of modifying facilities or handling different chemical forms – a State that is a technology owner will likely be more capable than a technology user.

As with misuse path steps, open sources are highly relevant to evaluating a state's technical capability to pursue **clandestine pathways**. However, there are considerably more degrees of freedom when assessing **clandestine** path steps that include the possibility of **indigenously produced** material and **imported** material and equipment, creating considerable uncertainties in the analytical process. Factors of production are variable in the long-run and assessments must evaluate the complex relationship between time, resources, and capability.[29] The resulting analytical uncertainties can be significant. For instance, a project that would have taken nearly two decades in peacetime was substantially accelerated to less than half that time during wartime by performing steps more quickly and in parallel.[32] Moreover, this was achieved over half a century ago during the Manhattan Project when very little was known of the basic physics and engineering challenges that are now well known.[33]

As noted by a recent study on latency, "if one uses [an engineering management] approach for specific known cases, the time predicted for a state to develop its first nuclear device tends to be incorrect" as "… pathway decisions are determined by various motivations and institutional impediments that often outweigh the pure engineering resource management decisions."[34] An academic study on US intelligence estimates of foreign nuclear programmes [35] suggests that underestimates of a state's nuclear capabilities can be comparable to the five year criterion used to judge technical plausibility. In other words, a capability judged to be five years away may exist in a state. Although the study refers to all-source assessments, there is no reason to think that the same does not apply to open source analyses.

3. Summary and Discussion

As presented in this paper, open source information collection and analysis can play a role in supporting the acquisition path analysis process. In particular, it can support/complement/inform the analysts on the technical capability of a State to set up and operate a given nuclear process in a given time frame. As summarized in Table 4, open sources play varying roles in an APA. While playing a limited role when evaluating diversion path steps, open sources may be the only source of information available to the IAEA when evaluating a state's capability to misuse declared facilities and pursue undeclared path steps. However, analysts must contend with two sources of uncertainties: informational and analytical. Information collected in the open source must be treated as potentially incomplete, unreliable, ambiguous, and deceptive. Moreover, the analytical processes can propagate these informational uncertainties to produce unreliable results. Historical evidence suggests that these errors may be large enough such that path steps judged to be implausible within the next five years may already exist within the State.

Table 4. APA information requirements, potential roles of open source, information uncertainties, and analytical uncertainties

Stage	Sub-Stage	Role of Open Source	Information Uncertainties	Analytical Uncertainties
Information collection		Contributes to all-source information collection	-	-
Path identification	Declared path steps	Corroboration of declarations	-	-
	Addition of feasible path steps	N/A (Physical Model identifies technological possibilities)	-	-
	Identification of plausible path steps	See technical capability	-	-
Technical capability	Indigenous production of pre-34(c) path steps	CSA-only states: main source of information CSA+AP: corroboration of state declarations	CSA-only: possibly unreliable and incomplete CSA+AP: not all activities may be declared	-
	Diversion path steps	State declarations are paramount, OS plays corroborating role	-	Mostly fixed production factors
	Misuse path steps	Informs assessment of capability to modify/exploit existing equipment	Denial and deception	Fixed and variable production factors
	Clandestine path steps and import	Informs assessment of state's capability	Denial and deception	Variable production factors
Estimating time	-	Informs assessment of the intrinsic difficulty of a step	Potentially misleading qualitative statements	Errors may be comparable to technical plausibility criterion

3.1. Some methodological considerations

Information coming from safeguards activities, including open source information can be considered being pieces of empirical evidence.[36], [37] Their use and their dependability will depend on both the framework in which they are used and on the nature of the piece of evidence.

It is possible to identify three main broad conditions in which a State could fall with respect of its technical capability to perform a given process:

1. The State has the necessary infrastructure in place to perform the process;
2. The State is capable of setting up the necessary infrastructure to perform the process;
3. The State can become capable of setting up the necessary infrastructure to perform the process.

In principle, the first condition can be demonstrated true. Depending on the process and safeguards framework, this might be either trivial (e.g. evidence of research and development activities related to the nuclear fuel cycle that do not make use of nuclear material in a CSA-only safeguards framework – the activities do not need to be declared by the State but, being fully licit, evidence of their existence is very easy to find) or close to being practically impossible (e.g. a clandestine processing activity at lab-scale). Indeed, many of the techniques to detect such infrastructure, when clandestine, are vulnerable to denial and deception efforts as outlined in Table 3. "The difference between intelligence and scientific research is that intelligence deals with a consciously deceptive adversary." [38]

Conditions number 2 and 3 would always require a degree of judgment due to the time limit imposed by the definition of technical plausibility. Past examples like the British Blue Streak programme [39] indicate how uncertain the process of mastering new hard technologies might be, even for advanced States with highly developed soft skills. Any type of empirical evidence connected to these conditions would have an informative power at most, and sound management of these uncertainties is required.

Outside an empirical science framework, the gathering of empirical evidence can still be very important and valuable, but the analysts making use of it should be aware that their ability to falsify or corroborate a statement has probably decayed and replaced by a much weaker ability to inform or support a hypothesis rather than unequivocally demonstrating truth. In other words, outside an empirical science framework empirical evidence can at most support a statement with a given likelihood, i.e. testing the truth of a statement instead of demonstrating it logically.

4. Conclusions

The IAEA State Level Concepts foresees the use of Acquisition Path Analysis to design a State-Level Approach for safeguards implementation. This paper reflects on the potential roles of open source information in the acquisition paths analysis process. Depending on the acquisition path analysis stage, the role of open source information could vary from corroboration of already known information (correctness of declarations) to the identification of potential undeclared nuclear activities (completeness of declarations). The nature of the evidence obtainable from open sources requires careful management of all potential sources of uncertainty, both informational and analytical.

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