Annex

An improved missile verification system

1. In its review of missile inspection practices, UNMOVIC has been refining its verification methods and approaches, based on the Commission's experience and lessons learned. UNMOVIC has also drawn on the work of a panel of external technical experts, convened in June 2005 to assess the missile aspects of the monitoring and verification plan (see the twenty-third quarterly report of UNMOVIC (S/2005/742)). An outline of this improved missile verification system is presented below, greater emphasis being given to describing aspects that provide for increased efficiency and less intrusiveness for on-site inspections while also minimizing the resources needed to ensure the effectiveness of the overall verification regime. While dealing with the overall system of improved missile monitoring, this paper focuses on the indigenous development, production or modification of missiles.

2. In 1991, Iraq was prohibited from developing and acquiring ballistic missiles with a range of more than 150 km.[1] No multilateral arrangements exist governing the development or acquisition of ballistic missiles. However, there are a number of instruments relating to the non-proliferation of ballistic missiles. These include the Missile Technology Control Regime and the Hague Code of Conduct against Ballistic Missile Proliferation. Both are voluntary associations of a number of States. The Missile Technology Control Regime limits the proliferation of missiles and related technology, while the Hague Code of Conduct increases transparency with respect to ballistic missile activities. However, only the United Nations has considerable practical experience in the multilateral monitoring and verification of missile and unmanned aerial vehicle activities, from which lessons may be drawn for future application.

Missile verification system

3. Although the Security Council, by resolution 687 (1991), originally imposed the prohibitions on Iraq referring only to "ballistic missiles", subsequent related documentation[2] clarified that this term extended to other unmanned aerial "means of delivery" — the terminology now generally used. The term "means of delivery" essentially comprises ballistic missiles, cruise missiles and unmanned aerial vehicles.[3] Unmanned aerial vehicles have become more of a concern in recent years as their numbers and types have proliferated and their potential for delivering weapons of mass destruction has become greater, owing to increases in their range and payload capabilities. They pose a number of new and challenging aspects.

4. The main concern in missile proliferation is range and payload capability. In 1991, the Security Council set a range limit for Iraq's missiles at 150 km regardless

[1] In resolution 1737 (2006), the Security Council decided that all States should take the necessary measures to prevent the supply, sale or transfer to a Member State of items, equipment, goods and technology related to ballistic programmes. Earlier, in resolution 1718 (2006), the Council decided that another Member State should suspend all activities related to and abandon its ballistic missile programme.

[2] In particular, S/22871/Rev.1 (the monitoring plan), and the revised annexes to document S/22871/Rev.1 contained in document S/1995/208.

[3] In the current text, the term "missile" or "delivery system" is taken to include all these, unless the sense denotes otherwise.

of payload. For the Missile Technology Control Regime, the range and payload threshold is 300 km and 500 kg respectively. The Hague Code of Conduct refers to "ballistic missiles" but no particular range or payload value is specified. One of the major challenges for verification of a missile development programme, irrespective of the particular limit values, is that essentially the same basic technologies and processes are involved in manufacturing missiles that comply with or exceed the given limit. Thus, the verification methodology must take this into account and be able to distinguish between any activity, which could be permitted or prohibited in the future.

5. The improved missile verification system is based on three elements, namely,

- Knowledge and understanding of relevant activities and related equipment
- Information on export/import of relevant goods
- Verification and monitoring of compliance.

Knowledge and understanding of relevant activities

6. In the experience of UNMOVIC, information needs to be collected on existing or planned missile projects and on activities associated with, or relevant to, missile programmes. This information can come from a number of sources, primarily from the State concerned and from inspections of facilities. Information secured from the State itself is of primary importance as it provides a basis for verification as well as confidence-building. The information should be provided by way of formal declarations and pertain to specified activities, equipments, facilities etc., and be both project-based and site-based. The information required in the declarations should be specified and supplied according to a format prepared for this purpose by the inspection agency. Use of an electronic template may reduce errors and facilitate processing.

7. Information acquired through inspections of various sites is likewise of prime importance. It can lead to confirmation of declared data as well as to the need for further verification activities and could result in uncovering undisclosed information.

8. In addition, collateral analysis of related technical documentation and public media (print media, Internet, etc.) as well as intelligence from Governments and overhead imagery (satellite, reconnaissance aircraft) can provide support. Analysis and assessment of such information could lead to the level of knowledge and understanding necessary to permit decisions on the monitoring system and judgements on compliance.

Export/import data

9. States engaged in the development of missiles may have to import or export complete missile systems, related parts, equipment or subsystems. Therefore, in any case where missile verification would be required the identification and tracking of these items would become a crucial component of the verification activities. The identification itself requires a suitable promulgated list of items and a mechanism for receiving the data. UNMOVIC has been reviewing the existing list of missile items described in document S/2001/560 (15 October 2001) which details those items notifiable to UNMOVIC by exporters and importers under Security Council

resolution 1051 (1996) concerning Iraq. In applying measures in the cases of the Democratic People's Republic of Korea and the Islamic Republic of Iran in 2006, under Security Council resolutions 1718 (2006) and 1737 (2006), regarding the export of all items that would contribute to their development of ballistic missiles, the Council used the Missile Technology Control Regime annex (a list of items, materials, equipment, goods and technology related to ballistic missile programmes), embedding its contents in document S/2006/815. It should be noted that document S/2001/560 is built upon that annex, with the addition of specific provisions for Iraq.

Verification and monitoring of compliance

10. The third element of the improved system under development by UNMOVIC involves verification, including on-site inspection. The process of verification, leading to complete and correct knowledge of the real situation, should involve the analysis of all information gathered by the inspection agency. Ideally, the principal means of successfully achieving this goal of complete and correct knowledge will be through inspections of relevant facilities to examine infrastructure, equipment, activities and records and interviewing personnel.

11. Verification through on-site inspections can range in frequency and degree of intrusiveness. A key feature of the improved missile verification system is that future inspections can be less intrusive and more efficient by using two complementary approaches:

(a) Basing the system on "critical points";

(b) Utilizing new sensor and identification technologies.

Critical points

12. In the Commission's experience, determining compliance with the obligation not to develop, manufacture, or acquire any proscribed missiles has required conducting verification activities in many areas. This has entailed an extensive programme of activities to obtain comprehensive information and oversight over each and every aspect relating to missiles and unmanned aerial vehicles and their supporting infrastructure falling within the verification domain. It has encompassed, for example, the identification, inventorying and constant surveillance of all the parts and subsystems of each type of delivery system, together with the associated means of production and testing. Such a verification system, essentially using a comprehensive approach, required extensive resources in terms of inspectors and equipment in order to be fully implemented.

13. A modified system involving "critical points" for missile verification is offered in recognition that at all stages involved in the acquisition of a delivery system — research and development, prototype testing, serial production and deployment — there are critical points that cannot be easily avoided or bypassed. Such points can be associated with technologies, processes or pieces of equipment that are indispensable for the acquisition or the testing of a delivery system. A critical point also needs to be able to supply significant verifiable data through inspections, cameras, sensors or other techniques. If these critical points are monitored properly, then other steps or activities that are part of the overall acquisition process may be less important for verification purposes. Concentrating monitoring activities on the

critical points will still achieve verification objectives just as effectively as using a comprehensive monitoring approach because monitoring at these points can provide the information required for verification purposes. These critical points will be the focus of the verification effort. In addition, the application of new advanced monitoring and sensor technologies at such points will allow the collection of data efficiently and less intrusively.

14. To identify and select the critical points it is necessary to fully understand the process of the development and production of a complete delivery system, including the technologies and the equipment involved, as well as alternative ways that could be used to acquire proscribed delivery systems. In general, a delivery system is composed of the following key subsystems:

- The propulsion system which can use solid or liquid propellant (for ballistic missiles and cruise missiles), turbojet engines (used in cruise missiles and unmanned aerial vehicles) or aircraft piston engines (for unmanned aerial vehicles)
- The guidance and control system, which provides the orientation and position of the missile during flight, and applies corrections to maintain the missile on the correct trajectory or flight path
- The payload, comprising items or material that are to be delivered.

15. Some important critical points in a verification system are those related to testing, since testing provides the most significant and reliable information on performance. Testing also covers all the stages in the missile acquisition programme from research, development and mass production and during the operational life. In particular, the static testing of rocket propulsion systems, both liquid propellant and solid propellant, is an important critical point during the development stage and also in production. Flight testing is also an important critical point for ballistic missiles and cruise missiles. In all cases, the configuration of the delivery system being tested (dimensions, payload or provision for payload, number and capacity of fuel tanks etc.), needs to be verified.

16. While static and flight testing are clearly important critical points, the concept of critical point monitoring can be more clearly illustrated by the following three examples. The first can be found in the production processes for a composite solid propellant propulsion system of a missile. A simplified flow chart for this process is presented in figure I. Shadowed boxes represent critical points.

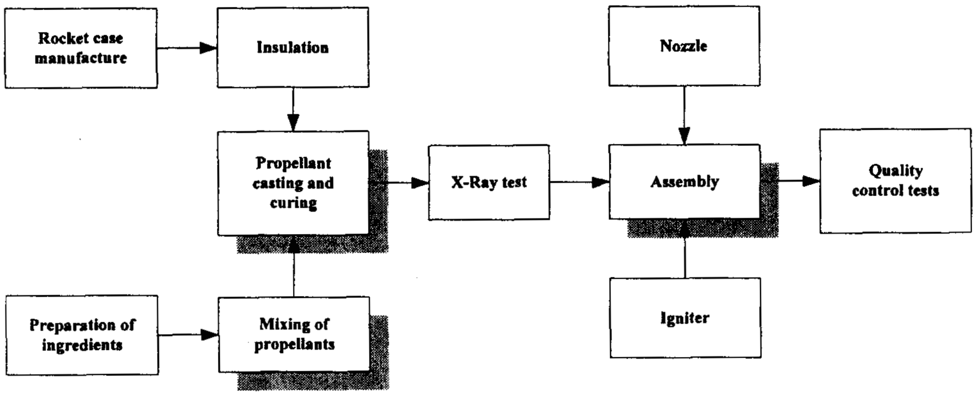

Figure I. Production flow chart for a composite solid propellant propulsion system

Each box of the flow chart represents a major step in the production process. Although each step is necessary, some are more significant from a verification viewpoint because they require very specific equipment or they are points of convergence. In the production flow chart in figure I, specific pieces of equipment are the propellant mixer and the propellant casting chamber where the rocket case is filled with propellant. These are necessary items that are usually co-located because of technical requirements. They will be few in number, if not unique, in the country. Points of convergence are represented by the propellant casting and curing step and the final assembly. The final assembly, for instance, is a critical point because it is where a number of subsystems are integrated, so that focusing on this point will provide corroboration of data from other facilities and will ensure knowledge on the configuration and quantity of missiles being produced. The steps identified above are all critical points. By contrast, other steps, for example the manufacture of the rocket case, do not require particularly specialized equipment and could be carried out in many and varied locations.

17. In developing a verification system, it is also recognized that not all critical points are of equal importance (although obtaining corroborative data from more than one is also necessary). For instance, in the production flow chart in figure I, both the propellant mixing and the propellant casting steps meet the definition of a critical point. Both critical points can provide information on the amount of propellant made and on its composition. In addition, though, information on the size and numbers of propulsion systems made can be obtained at the propellant casting step. This latter step is, therefore, the more useful of these two critical points to use in the verification system and the one where inspection resources should be concentrated.

18. Another example of using critical points is in the production of liquid propellant propulsion systems. A simplified flow chart for those systems, based on flow forming technology, is shown in figure II. The shadowed boxes represent critical points.

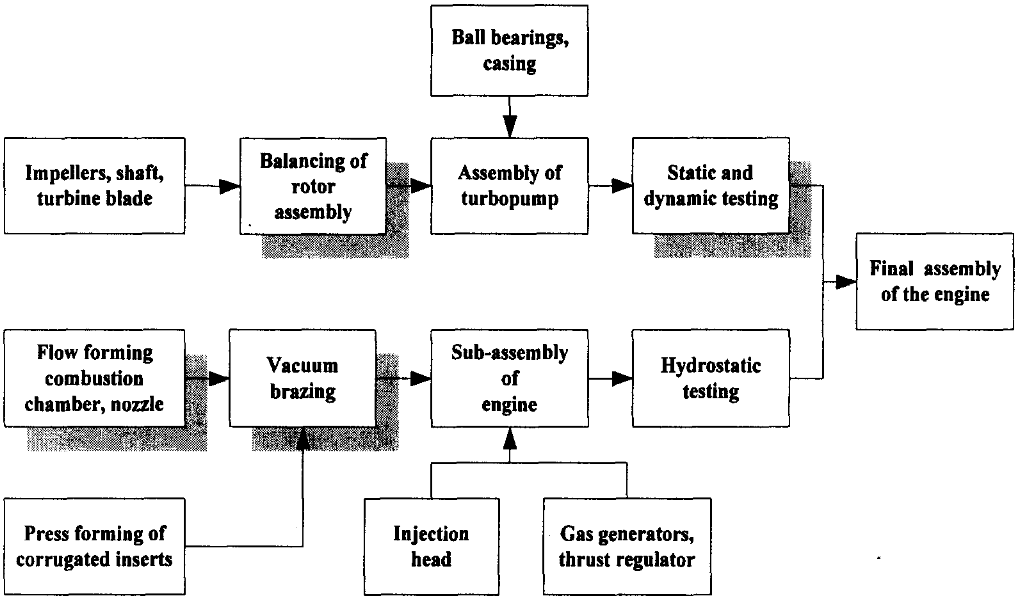

Figure II. Production flow chart for a liquid propellant propulsion system

19. In comparison with solid propellant propulsion systems, liquid propellant engine production involves a more extensive infrastructure. A liquid propellant engine consists of a large number of parts that have to be produced and joined together and there are many operations and tests that have to be conducted during this process. The production of all those parts employs numerous general purpose machine tools that can be distributed in many different workshops and in different facilities. An effective way of properly observing this process is to focus on the special machines and their fixtures that are required. In the flow chart in figure II, these are flow forming machines, vacuum brazing furnaces, balancing machines and turbopump testing stations. Those are specialized pieces of equipment that are few in number and their dimensions and operating cycles provide important data in regard to the dimensions and numbers of engines produced. These represent the critical points in this process. In this particular example, all the critical points identified are equal in importance and all of them have to be covered in order to provide a high degree of confidence.

20. In addition to the propulsion system, another major part of a delivery system is its guidance and control system. A simplified production flow chart for guidance and control units is shown in figure III. Again the shadowed boxes represent critical points.

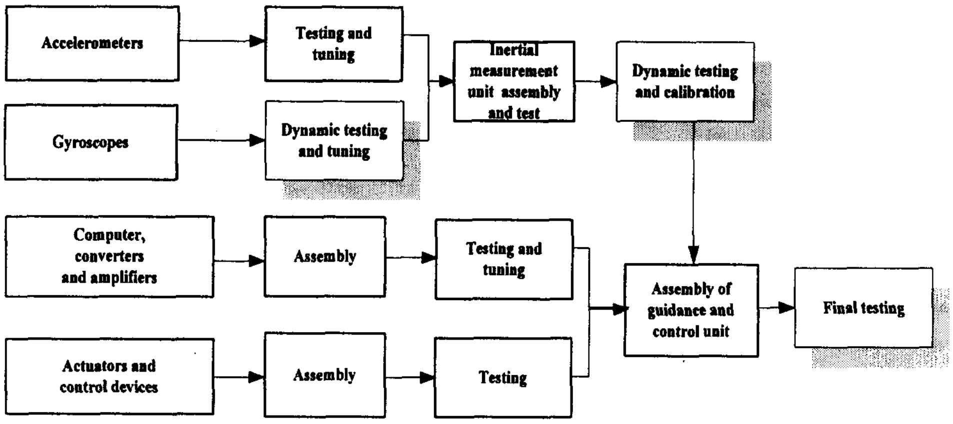

Figure III. Production flow chart for guidance and control units

In the generic production process of a guidance and control unit, as shown in figure III, there are steps that require specialized pieces of equipment. These include measuring equipment (such as multi-axis drift rate tables) for dynamic testing and calibration of the inertial measurement units and larger, more complex dynamic test stands for final testing of the complete guidance and control system. The steps where these pieces of equipment are used constitute critical points in the process of producing guidance and control systems. In figure III, these are shown as shadowed boxes. By focusing attention on those points through inspections, supplemented by the use of video cameras, other suitable sensors and tags, those points would provide key information for the verification of the types and numbers of guidance and control systems produced.

21. Unmanned aerial vehicles are included as one of the means of delivery because of their potential to deliver biological warfare agents in particular, although they could also be used for chemical warfare agents, and even nuclear payloads could be possible. Unmanned aerial vehicles present a particular challenge. Their challenge derives not only from difficulties in covering and observing flight tests, but principally from the following factors: (a) the relative ease with which they could be reconfigured, i.e. both modified to extend the vehicles' range beyond the permitted limit and modified to carry a weapons of mass destruction payload; (b) the fact that an effective biological payload can be as small as 20 litres and hence carried on quite small unmanned aerial vehicles; and (c) the fact that an unmanned aerial vehicle can fly by remote control or autonomously using an autopilot, to increasing ranges. A further factor is the vast array of vehicle types, applications, designs and sizes. Currently unmanned aerial vehicles are principally used for surveillance and reconnaissance, as target drones and, also, for electronic warfare; some vehicles can carry conventional weapons to give them a strike capability.

22. It is more difficult to find useful critical points in the production of unmanned aerial vehicles, compared to ballistic missiles and cruise missiles, basically because their production involves more generic types of equipment and many of the parts are commonly available. Nevertheless, a critical feature which is common to all unmanned aerial vehicles, however acquired, is their guidance and control system, which gives them the ability to fly autonomously to a designated location. The panel

of external technical experts convened by UNMOVIC in 2005 recommended that this system should be the focus, where critical points can be identified, for the verification of unmanned aerial vehicles both in assembly and under deployment. However, as a consequence of the rapid evolution of technologies, today essential components for guidance and control and even pre-assembled autopilots are available commercially. Although such parts may provide only low performance, they are still suitable for unmanned aerial vehicles if associated with an update system. This is not so for ballistic missiles which require higher performances because they are not equipped with an update system and are exposed to a more demanding operational environment. In addition, other features such as the maximum take-off weight capacity, the ease with which it can be reconfigured and the propulsion system should be considered in assessing the range of an unmanned aerial vehicle.

New technologies

23. An important factor for consideration in the selection or choice of critical points for incorporation in the verification system is the potential use of sensors. An underlying question to be answered is whether a certain critical point is suitable for the use of a sensor and whether there is an appropriate sensor available that will provide the information required. The difficulty in installing the sensor needs to be assessed, as does whether any sensor installed would cause unacceptable interference to the operation being observed. The reliability of the sensor and the ease with which it might be compromised are also factors. However, the use of sensors cannot only reduce the presence of inspectors on site but can also provide more complete coverage. Some new developments in potentially useful sensors are being explored by UNMOVIC.

24. Technologies being investigated include mechanical vibration sensors, sound sensors, infrasound sensors, programmable surveillance cameras, smart tags, wireless technology and digital memory devices. Sensors using these new technologies could have application in monitoring manufacturing processes, static testing of missile propulsion systems and flight tests of missiles. For example, both mechanical vibration sensors and sound sensors can, in principle, be used to "fingerprint" declared operations on pieces of equipment at critical points and could thus be used to verify the equipment's use. Infrasound sensors, already used in the detection of nuclear tests, offer the potential for use in remotely detecting flight testing and even static testing of ballistic missiles. Modern surveillance camera systems provide many features such as scene anomaly detection, shape recognition, automatic triggering based on a range of user-defined criteria and scene authentication to ensure that images have not been modified or compromised, all of which can be usefully applied in verification activities. Smart tags (radio frequency identification tags) permit a time-saving and non-intrusive way of maintaining inventory oversight of important items such as selected machinery, specialized components and missiles. Modern wireless technology allows for remote collection and transmission of data derived from sensors, thus improving coverage of data collection and giving faster access to information, while permitting a reduction in the presence of inspectors in facilities.

Ongoing work

25. The combined use of critical points and new or advanced technologies in inspection and verification can provide more directed and focused information and permit remote acquisition and transmission of data. They can also allow a reduction in both the number and the footprint of inspectors, thus providing more resource-efficient and less intrusive inspections. These new technologies are being further explored by UNMOVIC. The improved monitoring system outlined here, together with other studies conducted by UNMOVIC, such as the use of indicators (described in the twenty-seventh quarterly report of UNMOVIC (S/2006/912)), are contributing to the development of a more effective United Nations verification and inspection capability.