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IAEA Safeguards: Implementation Blueprint of Commercial Satellite Imagery

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IAEA Safeguards: Implementation Blueprint of Commercial Satellite Imagery

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Table of Contents

Executive Summary

Safeguards by Open Sources

The International Atomic Energy Agency's Safeguards System has evolved over the past 30 years and has been strengthened through the continuing introduction of new methods and techniques.

A major milestone in the efforts to strengthen the Safeguards System was reached in May 1997 when the Board of Governors approved a 'Model Protocol Additional to Safeguards Agreements'. The Protocol provides the legal basis necessary to enhance the Agency's ability to detect undeclared nuclear material and activities by using information available from open sources to complement the declarations made by Member States.

Commercially available high-resolution satellite data has emerged as one potential complementary open information source to support the traditional and extensive Safeguard activities of IAEA.

The Study and the Report

This document – *IAEA Safeguards: Implementation Blueprint of Commercial Satellite Imagery* - constitutes the second report from SSC Satellitbild giving a structured view and solid guidelines on how to proceed with a conceivable implementation of satellite imagery to support Safeguards activities of the Agency.

The basis for the implementation guidelines is the concept presented in the Phase 1 study of creating a new, efficient and relatively small Imagery Unit within the IAEA capable of performing advanced image processing as a tool for various safeguards tasks. In addition, the initial cost/benefit simulation results from the Phase 1 report have been further elaborated in this Phase 2 study by including several alternative ways of dimensioning the capacity of the Imagery Unit

This Phase 2 report presents a large number of concrete recommendations regarding suggested management issues, work organisation, imagery purchasing and team building. The study has also resulted in several lists of actions and preliminary project plans with GANT schedules concerning training, hardware and software, as well as for the initial pilot studies.

Major Findings

In both the Phase 1 and Phase 2 studies it is confirmed that the proposed concept of a relatively small Imagery Unit using high-resolution data will be a *sound and feasible undertaking*. Such a unit capable of performing advanced image processing as a tool for various safeguard tasks will give the Agency an effective instrument for reference, monitoring, verification, and detection of declared and undeclared activities.

The total cost for implementing commercial satellite imagery at the Department for Safeguards, as simulated in these studies, is approximately *MUSD 1,5* per year. This cost is founded on an activity scenario with a staff of 4 experts working in an *IAEA*

Imagery Unit with a workload of three dossiers or “issues” per week. The imagery unit is built around an advanced PC image processing system capable of handling several hundreds of pre-processed images per year. Alternatively a *Reduced Scenario* with a staff of 3 would need a budget of approximately *MUSD 0,9* per year, whereas an *Enhanced Imagery Unit* including 5 experts and a considerably enlarged capacity would cost *MUSD 1,7 per year*.

The Imagery Unit should be organised so it clearly reflects the objectives and role as set by the Member States and the management of the Agency. We recommend the Imagery Unit to be *organised into four main work areas*: production of ‘dossiers’; generation of reference information; monitoring and verification; and finally organisation of an imagery database. Each work area could be dedicated to one staff member running one of the four main tasks.

We recommend the Agency to *introduce a full service imagery supply routine*, where the image supplier(s) take the responsibility and risks in delivering the best possible set of imagery from a chosen facility. This routine should be the basis for an effective imagery purchasing approach at the Unit. Successful negotiations regarding price and service with the suppliers will substantially influence the overall cost.

The implementation of the satellite imagery system is suggested to be performed in a controlled way, by *creating clear implementation phases with firm milestones*, and by evaluating each step before going further:

- Initial phase – 6-12 months
- Pre-operational phase – 1-2 years
- Operational phase – after 3 years.

The significant *customisation* of the Imagery Unit system that is envisaged must be well *specified and documented*.

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Sammanfattning

Användning av öppna källor inom safeguard

Safeguardsystemet inom den Internationella Atomenergiorganisationen IAEA har utvecklats och förstärkts kontinuerligt under de senaste 30 åren genom införande av nya metoder och ny teknik.

En milstolpe i arbetet med att förstärka safeguardsystemet nåddes i maj 1997 när IAEA:s generalförsamling antog "Modell för tilläggsprotokoll till safeguardavtalen". Protokollet ger den nödvändiga legala grunden för att öka möjligheten för IAEA att upptäcka odeklarerat klyvbart material och odeklarerade kärntekniska aktiviteter genom att utnyttja information från öppna källor som komplement till medlemsstaternas officiella deklarationer. Högupplösande satellitdata som är kommersiellt tillgängliga kan vara en sådan kompletterande öppen informationskälla som stöd för IAEA:s traditionella och utökade aktiviteter inom safeguardområdet.

Undersökningen och rapporten

Denna rapport - *IAEA Safeguards: Implementation Blueprint of Commercial Satellite Imagery* - är den andra rapporten från SSC Satellitbild och ger en strukturerad bild och klara riktlinjer för hur användningen av satellitdata kan implementeras som stöd för IAEA:s safeguardaktiviteter.

Riktlinjerna för implementeringen utgår ifrån det koncept som presenterades i Fas 1-undersökningen innebärande en rekommendation att skapa en ny, effektiv och relativt liten bildbehandlingsenhet inom IAEA som kan utföra avancerad bildbehandling för olika safeguardändamål. Dessutom har resultaten från den preliminära kostnads- och lönsamhetsanalysen från Fas 1-rapporten vidareutvecklats i denna Fas 2-undersökning genom att inkludera flera möjliga sätt att dimensionera bildbehandlingsenhetens kapacitet.

Denna Fas 2-rapport innehåller ett stort antal konkreta förslag gällande arbetsledning, arbetets organisation, inköp av satellitbilder och skapandet av en bildbehandlingsenhet. Undersökningen har också resulterat i flera listor över uppgifter och preliminära projektplaner med GANT-scheman gällande utbildning, hård- och mjukvara, samt planer för preliminära pilotstudier.

Resultat

Både Fas 1- och Fas 2-undersökningarna bekräftar att det föreslagna konceptet med en relativt liten bildbehandlingsenhet som använder högupplösande data kan bli en *fungerande och genomförbar verksamhet*. En sådan enhet som kan utföra avancerad bildbehandling för olika safeguardändamål kan förse IAEA med ett effektivt instrument för hantering av referensinformation, övervakning, verifiering och upptäckt av deklarerade såväl som odeklarerade aktiviteter.

Totalkostnaden för att införa kommersiell satellitövervakning inom IAEA safeguard, såsom simulerat i dessa undersökningar, uppskattas till *1,5 MUSD* per år. Denna kostnad baseras på skapandet av en bildbehandlingsenhet på IAEA bestående av 4 experter och en arbetsvolym om tre "dossier" per vecka. Bildbehandlingsenheten förutsätts ha tillgång till ett avancerat PC bildbehandlingssystem som klarar av att behandla flera hundra förprocessade bilder per år. Alternativt skulle en *Reducerad enhet* med 3 anställda kräva en budget på cirka *0,9 MUSD*, medan en *Utökad enhet* med 5 experter och en betydligt större kapacitet skulle kosta *1,7 MUSD* per år.

Bildbehandlingsenheten bör organiseras på ett sådant sätt att den tydligt avspeglar de syften och den roll medlemsstaterna och IAEA:s ledning bestämt. Vi föreslår att bildbehandlingsenheten *organiseras i fyra huvudområden*: produktion av "dossier", generering av referensinformation, övervakning och verifiering och slutligen organisation av en databas. Varje arbetsområde kan vara tilldelat en expert som ansvarar för en av de fyra uppgifterna.

Vi föreslår att IAEA *inför en heltäckande inköpsrutin för anskaffande av satellitbilder*, där dataleverantören (dataleverantörerna) tar totalansvaret för att leverera bästa möjliga dataset från den utvalda anläggningen. Denna rutin bör utgöra grunden för en effektiv inköpsstrategi vid enheten. Framgångsrika förhandlingar med leverantörerna gällande pris och service kommer att kunna ha stor påverkan på totalkostnaden.

Implementering av satellitdatasystemet föreslås ske på ett kontrollerat sätt, *genom att skapa tydliga implementeringsfaser och fasta milstolpar* och genom att utvärdera varje steg innan man går vidare:

- Preliminär fas - 6-12 månader
- Pre-operativ fas - 1-2 år
- Operativ fas - efter 3 år

Den betydande specialanpassning av bildbehandlingsenhetens system som förutses måste *specificeras och dokumenteras* väl.

INTRODUCTION AND OVERVIEW

Introduction

Purpose of the Document

This document presents the results of an implementation study for commercial satellite imagery conducted by SSC Satellitbild for the International Atomic Energy Agency (IAEA).

Task Description

The aim of the SSC Satellitbild work is to provide supporting information as guidance for implementation actions by IAEA regarding the introduction of satellite-based methods within the Agency's Safeguards programme and specifically to assist the Strengthened Safeguard System.

Document Description

This document is divided into the following chapters:

1. Executive summary.
2. Introduction and overview – this chapter.
3. Action and opportunities of the 'Imagery Unit' – provides an overview of the current situation, suggest objectives for the Agency and opportunities offered by commercial satellite imagery.
4. Safeguards applications, Work flow and procedures – describes the overall concept of remote sensing as well as applications and methods used in intelligence work.
5. Staff and competence development – gives highlights and advice regarding recruitment and training of staff to the Imagery Unit.
6. Imagery and security issues – outlines a scheme for the purchasing of data, including a method for security management.
7. Equipment, data storage and localities – presents lists and suggestions for hardware, software and other functions.
8. Project plan for implementation – describes the steps necessary during implementation.
9. Initial Phase, Pilot studies – lists the activities necessary for the pilot studies.
10. Cost simulation – presents an extension to the Phase 1 study including calculations for different sized Imagery Units and costs for the Initial Phase implementation.
11. Conclusions – presents the conclusions from the work conducted.
12. List of literature – lists the documentation consulted during this study.

Swedish Support Program

This study has been performed and financed as a part of the Swedish Support Programme managed and co-ordinated by the Swedish Nuclear Power Inspectorate (SKI).

Issue Definition

Study Context

As a consequence of the new open source information policy, the Agency has started a series of case studies and workshops to analyse the potential capacity and efficiency for safeguards offered by commercial satellite imagery systems. The overall aim of this investigation is to give the IAEA a more comprehensive understanding of the topic to enable a proper planning and decision process.

The investigation is being performed in accordance with an IAEA Departmental Work Plan. Some intermediate study results have already been compiled and reviewed during Technical Workshops. Moreover, advice from invited experts and experience from international organisations similar to IAEA have also been included in the process. The investigation addresses technical aspects, legal and policy issues, as well as a cost/benefit analysis justifying resources to be allocated. A document *Safeguards: Sources and Applications of Commercial Satellite Imagery* will be the final outcome of the investigation and establish the framework for further actions.

Based on these actions, it will then be possible to compile an *Implementation Plan* that structures the tasks and steps to be taken by IAEA for an efficient and successful implementation of satellite imagery applications. The Implementation Plan is proposed to be operational and task-oriented, and will include organisational aspects as well as technical questions.

Implementation Blueprint

The study logic for the Swedish support work for the Agency, as carried out by SSC Satellitbild, is shown in Figure 1 below. This figure delineates a two-phase study and the tasks included. Input information and deliverables are also shown.

This report – IAEA *Safeguards: Implementation Blueprint of Commercial Satellite Imagery* - constitutes the result from Phase 2 of the SSC Satellitbild support. The Phase 2 study has generated a structured "blueprint" report as a discussion paper for the implementation of satellite imagery safeguards at the IAEA. The "Implementation Blueprint" document has been outlined in close co-operation and interaction with the staff of the Agency.

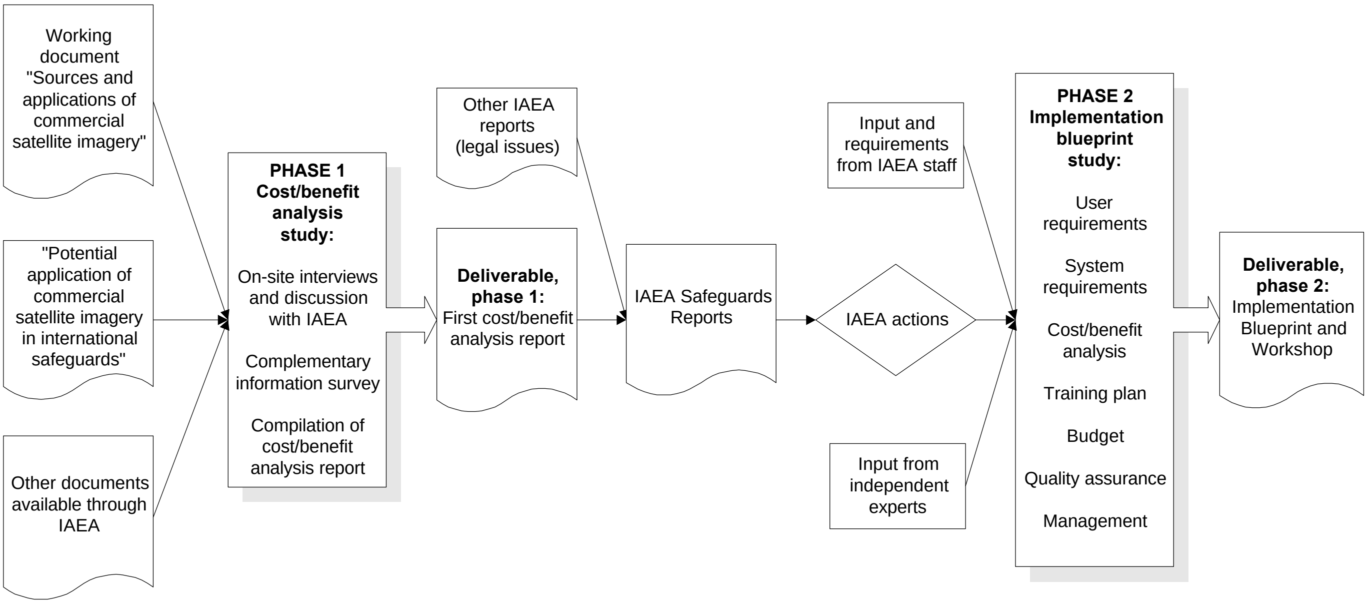

Figure 1. *The study logic.*

Objective of the Study

The objective for the SSC Satellitbild support work during Phase 1 has been the following:

To conduct a first cost/benefit analysis to be used as support information for paragraph V chapter 7 *Cost/Benefit Analysis* in the IAEA document *Safeguards: Sources and applications of commercial satellite imagery* as guidance for implementation actions by IAEA. The cost/benefit analysis will clearly indicate in which safeguard applications the utilisation of satellite data as information source will provide the greatest benefit in relation to the estimated cost.

The objective for the SSC Satellitbild support work during Phase 2 is the following:

To perform an implementation study, and compile a structured plan thereof, as a basis for an efficient and progressive implementation of satellite imagery at the IAEA. The resulting report and presentation of advice and recommendations will be utilised as an ‘Implementation Blueprint’ in the internal discussions and the review process of the Agency. The study should address the following topics: project structure and management, user and system requirements, data delivery and security, training, quality assurance, and cost/budget analysis.

Actions and opportunities of the ″Imagery Unit″

Introduction

This chapter provides an overview of an Imagery Unit for the IAEA, its objectives, role and possible organisation. While used in the singular, the term “Imagery Unit” (IU) does not in itself imply a single or exclude multiple such units. The alternatives for the number and organisation of the Imagery Unit are discussed within this chapter.

Background

There are a number of reasons why it is particularly appropriate today to be considering the implementation of satellite imagery by the establishment of an Imagery Unit. The roots of these reasons lie partly outside the Agency’s immediate environment, in what can be called its macro-environment, and partly as an intimate part of the Agency’s own organisation and way of working.

Macro-Environment - New Opportunities

Developments within the Agency’s macro-environment create new opportunities that are of specific relevance in the consideration of an Imagery Unit.

New Satellites

Especially based on the recent success by Space Imaging in launching the civilian IKONOS satellites capable of acquiring high-resolution quality imagery, it is clear that several such systems will become operational during 1999 and 2000. These satellites will all provide imagery with a spatial resolution of about 1 metre under normal commercial terms and conditions. By 2001 up to four such satellites are expected to be in operation from three different commercial operators.

Imagery with equivalent characteristics has been assessed by the Agency and has a clear potential to act as a complementary source of information. The growing number of commercial operators that plan to offer such imagery will likely lead to price reductions so that this information source will become progressively more attractive.

Better IT/GIS

Desktop computer systems have now reached such a level of development that image processing tools and geographic information systems are accessible to anyone with a mid-range PC. In addition, the price and availability of high-volume hard disks and CD-ROM readers and writers are also such that the large data volumes associated with satellite imagery are today manageable at a reasonable cost. From the Agency’s perspective, this means increasingly lower start-up costs for equipment and operational costs for practical data storage and access. In the past these issues have been major technical and financial barriers for many users to adopt satellite imagery in operational activities.

Internal Environment Need for Increased Effectiveness and Efficiency

Expanding responsibilities and a budget that is shrinking in real terms are two major drives behind the need for increased effectiveness and efficiency within the Agency. These two objectives are interdependent and it is essential that they are addressed in parallel. This is a requirement if the potential benefits of increased efficiency and productivity are to be realised. This can only be achieved through an improved effectiveness based on clearly defined and prioritised goals.

Expanded Mandate (The Additional Protocol)

The Additional Protocol has so far been ratified by only a small number of Member States (e.g. Australia), but more and more Member States are expected to follow in the future. The Additional Protocol primarily involves the submission of information about sites and activities that have not previously been part of the Agency’s responsibility. It also makes available other means and principles for the Agency to perform its duties, including the right to seek out undeclared activities in cases where these are suspected.

The consequences of the Additional Protocol are uncertain, but an increase in the Agency’s workload cannot be excluded. This is at least probable in the short to medium term as Member States ratify the agreement, thereby creating the need for the Agency to process, verify and complement the documentation of previously undeclared sites and facilities.

Satellite imagery can contribute in the early period after the Additional Protocol is signed by providing documentation of facilities not previously covered by an Agency agreement and helping confirm their operational status. It can also help in the identification of undeclared activities. In this latter role satellite imagery is best used in the confirmation and verification of other material. In this way the Agency’s effectiveness can be increased through the use of satellite imagery.

Static Budget

The Agency’s budget has remained at the same level in absolute terms for several years. At the same time, initiatives such as the Additional Protocol involve changes in the way the Agency works. Such changes involve one-time costs plus a potential increase in the Agency’s workload. Thus the performance expected from the Agency is increasing at the same time as the Agency’s budget is shrinking in real terms. Changes are therefore necessary in the way in which the Agency works so that the available resources go farther.

Objectives of the Imagery Unit

The implementation of satellite imagery and the creation of an efficient Imagery Unit (IU) must have a clear set of objectives - firstly if it is to be a success, and secondly if it is to be judged to be a success. The IU’s impact on the Agency’s operations can be gauged against such objectives, and its activities more easily focused with the objectives in view.

The objectives of the Imagery Unit need to fulfil a number of criteria:

- clear, realistic and understood by all involved
- expressed in measurable terms
- defined with specific time limits
- ranked by priority
- co-ordinated with the Agency's other objectives.

The objectives need to be clear and understood by all so that all efforts are directed towards the same goal. Realistic objectives make it easier to engage personnel and provide good possibilities to succeed.

Expressing the objectives in measurable terms means that progress can more easily be measured and understood. Measurable objectives provide a tool giving an early insight in the case of problems arising. Meanwhile, less specific expressions of an objective can be subject to later interpretations that change the criteria for success.

To clearly define objectives with time limits provides a set of more significant milestones against which progress can be checked. They also help provide details in a vision for the Imagery Unit that is expressed in terms of what capabilities and results are to be achieved and when it can be accomplished.

A ranking of the various objectives by priority is essential since all objectives are not equally important for the success of the Imagery Unit. In addition, the time aspect of each objective means that the short-term objectives need to be prioritised in the coming period.

The need to co-ordinate the Imagery Unit's objectives with the Agency's other objectives arises as a natural consequence of the fact that the IU has the potential to contribute to a wide range of different organisational objectives. A number of more or less obvious areas where the IU could contribute to the Agency's objectives are:

- Operational objectives – support to inspectors leading to increased effectiveness & efficiency
- Competence objectives – in-house technical competence capabilities versus those to be bought-in
- Cost objectives – changes in cost breakdown, total costs and with respect to benefits
- Capacity objectives – ability to process quantities of imagery/dossiers per year
- Communication objectives – building external confidence and potential deterrent.

Recommendations

We recommend that the Agency clearly and in measurable terms define, document and distribute the objectives of the Imagery Unit internally to all concerned and to the Member States.

We also recommend that the objectives of the Imagery Unit should be expressed and documented in such a way that Management of the Safeguards and the Team Leader of the IU will be given both certain mandate and long term guidelines to accomplish their duties.

Role

There are a number of roles that can be fulfilled by the Imagery Unit in the context of the objectives mentioned above.

Support to Inspections

The Imagery Unit is a support unit for the operational entities within the Agency. It provides integrated access to geographical information in the form of satellite imagery, maps and other spatial data and expertise in their use for fulfilling the Agency's objectives.

Reactive and Proactive Roles

The Imagery Unit can have both reactive and proactive roles within the operational activities of the Agency. The reactive role of the IU is in response to requests for verification or further information about a specific site from the operations divisions or Agency management. A proactive role for the IU is the search for undeclared sites or activities, or monitoring of known sites, according to a pre-defined strategy.

Examples of such pro-active strategies can be handled by:

- random sampling covering all suspected areas within a certain time period
- intensive 'campaigns' covering a specific and sensitive part of the nuclear weapon chain
- pro-active search of other open sources leading to an immediate action of intense monitoring

Decision Support and Visualisation

The majority of information provided by the Imagery Unit will be in the form of images, maps and graphics. The combination of different types of spatial information in a single visual presentation is a powerful method of analysis. Such material is a complement to other Agency information in decision support.

Deterrent Role

The careful and planned release of information about the establishment of an Imagery Unit and the Agency's enhanced capabilities to verify declarations and detect undeclared activities may act as a deterrent. In order for this potential to be realised this goal and a strategy to reach it need to be developed within the context of a total communications strategy as outlined above.

Contribution to a Positive Public Image

The establishment and operation of the Imaging Unit will enhance the Agency's detection and verification capabilities. In this way it has the potential to contribute to building confidence in the Agency and its capability to carry out its duties among organisations and observers outside the Agency. In order for this potential to be realised the Agency needs to be proactive in presenting information about the development and operation of the IU. This should be done in the context of a total communication strategy that includes as one of its aims to build up a positive public perception of the Agency.

Source of Illustrative Material

The graphical format of the IU's spatial information is well suited to general illustrative purposes. Examples of such uses include visualisations as illustrative material in contacts with the public and press.

Recommendation

We recommend the Agency to reach a consensus as regards the internal and external role of the Imagery Unit. It is especially important that the interface and the ways and means interaction between the IU and other units within the Agency are well specified.

We recommend the Agency to use all available means – both technical and organisational – to facilitate a correct communication between the IU and other relevant units.

Imagery Unit Structure

Potential Structures

The Imagery Unit can be established as either a centralised or a decentralised function, or as a hybrid of these two models.

Centralised Imagery Unit

A centralised IU would offer personnel, equipment and competence in a single entity available as a resource to all operational entities. In this way all of the experience and capabilities available within the Agency in the use of satellite imagery and its combination with other information would be available to all cases. Only a limited number of specialist personnel would be required, and it would be easier to ensure a maximum level of utilisation of the resource. On the other hand, a centralised IU would be problematical in relation to the Agency's requirement to be restrictive about Members States' information to the respective operations divisions. In the case of many simultaneous requests for support priority conflicts could arise for the Imagery Unit's resources.

Table 1. *Centralised Imagery Unit: Advantages and Disadvantages*

Advantages	Disadvantages
Agency's total competence available for all cases	Difficult to ensure information confidentiality
Minimum possible personnel and equipment costs	Can experience priority conflicts in periods of many simultaneous requests for support
Maximum resource utilisation	
Lowest possible cost	

Decentralised Imagery Unit

A decentralised approach to the Imagery Unit would mean a dedicated IU for each operational entity that is to have the IU capability. For more than one operational entity to have this capability more Imagery Units are created, one for each of the operational entities concerned.

Each decentralised IU would be a self-contained team possessing the full complement of personnel and competence required for an IU, as well as to the same tools. In this model a possible scenario is one IU for each operations division. This latter solution would circumvent problems of information confidentiality, since each team would only work with a selection of the Member States as per the operations divisions today. The availability of a complete IU capability within each division would also offer a higher level of dedicated preparedness and expertise in the issues most relevant within each division. However, it might be difficult to ensure that all of the teams are fully utilised, depending upon the specific conditions within each operations division. Maintaining several complete teams would also be more costly than a single team, even if it were possible to share centralised equipment and data storage.

Table 2. *Decentralised Imagery Unit: Advantages and Disadvantages*

Advantages	**Disadvantages**
Easier to ensure information confidentiality	Only part of Agency's competence available for each case
Higher level of dedicated preparedness in each operations division	More personnel – duplicate staff for each IU
Development of specific expertise relevant to work in each operations division	Difficult to ensure full utilisation of each IU
	Higher total cost for IU capability

Hybrid Imagery Unit

Between the fully centralised and fully decentralised options is a range of other possibilities. The availability of central facilities, such as specialist equipment that is used only on a relatively infrequent basis, is one possible element of a hybrid solution. It is also possible that some processing of data over some of the Member States is considered so uncontroversial that these can be handled together in a central unit while more sensitive areas are dealt with by decentralised facilities on the basis of the operations divisions.

Path to Sustainable Structure

Despite the completion of a number of internal and Support Programme studies demonstrating the utility of commercial satellite imagery to the Agency, the Agency itself needs to build up its own experience and competence in the use of satellite imagery. This is an essential step in order for the Agency best to be able to see how to integrate the new possibilities with existing structures and routines.

The phased introduction of an Imagery Unit needs to be carefully planned in order to ensure that maximum benefit arises. To ensure this, it is suggested here that the path towards a fully developed operational capability pass through a number of stages:

- Initial phase – 6-12 months
- Pre-operational phase – 1-2 years
- Operational phase – after 3 years.

Each phase should include some lessons learned to guide the next phase. These stages are further described in chapter 8.2.

Evaluation Opportunities

In addition to the relatively informal feedback sessions as described above, it is also important that a more formal review and recommendation process is established for the development phases of the IU. This concept can and should then be continued as an integral part of the operational procedures of the IU. These reviews should include the documentation and discussion of experiences in co-operation with management. In this way the lessons that are available from past experiences are noted, learned from and practical measures are taken to improve processes and methods for the future. Major review milestones such as these should at least occur at the end of each major phase, and preferably every six months.

Recommendations

We recommend that the Department of Safeguards in an early stage of the implementation build up its own hands-on experience in the use of satellite imagery with practical case studies.

We recommend a phased implementation of satellite imagery in three steps. Each phase should be reviewed and lessons learned should be noted to guide the next phase. The entity utilising the imagery in support of the inspectors could be based on either a centralised or decentralised Imagery Unit. The IU should be organised with a self-contained team and with technical capacity to fulfil all the applications as defined by the Agency.

A decision for choosing a centralised or decentralised IU solution does not need to be taken until experiences from the Initial Phase have been obtained.

Safeguards applications - Workflow and procedures

Introduction

In several reports, produced by the Agency in-house or for the Agency on behalf of Member States, the possibilities for use of satellite image interpretation for Safeguards applications have been discussed. From these reports, it is abundantly clear that the use of satellite image interpretation is a tool that could be used to increase the efficiency of the Agency's activities. It is also evident from these reports that satellite image interpretation would be most useful as a tool complementing other methods currently used for Safeguards applications, forming an integral part of these activities by the Agency. This approach of satellite image interpretation complementing and supporting rather than completely replacing today's activities, has been the guiding star also when producing the current Phase 2 study.

Building upon the earlier work, the current study aims at recommending an overall organisation for the Imagery Unit, workflow and procedures for the use of satellite imagery for the unit staff, but also dealing with the details of how to practically implement the techniques. This chapter is therefore organised to describe and recommend in what way the IU can be realised from several viewpoints; recommended general work organisation; anticipated applications; suggested data processing and workflow; typical input/output list; and finally as a fictitious case study.

Work Organisation of the Imagery Unit

An efficient and sustainable utilisation of satellite imagery requires a stable and consequent assignment from the Agency. The hands-on experience and the special knowledge within imagery based safeguards monitoring will take several years to establish and comprehend. Thus, it is important that the staff from the beginning is organised in accordance with the stated objectives and role of the Imagery Unit. We suggest the following four main tasks (work areas) for the Imagery Unit as shown in figure 2 and described below.

A. Produce and update **digital Dossiers** for specific Safeguards issues. These issues concern the confirmation and/or assessment of other types of information regarding facilities under Safeguards.

   The work is *task-oriented* and should to a high degree *be directed by the ordinary Safeguards operation*.

B. **Logistic support** by producing planning and **reference information** for inspections as a complement to available maps, and to support inspectors in the field. Data should be distributed and used as digital GIS information layers for most efficient use of both the imagery and the map information.

   This is a typical *long-term* task requiring an overview of all maps and images. Thus, *needs and requirements of the IU work should guide* the building up of the reference information.

C. **General monitoring** of ongoing Member State activities by performing change detection and detection of undeclared facilities as an additional and complementary tool to other Agency Safeguards operations.

   The work is *campaign-oriented* and will be *directed by specific Safeguards actions* or by initiative of the IU itself.

D. Browse, purchase and **organise an imagery database** of satellite data to build up an efficient IAEA imagery library. To be able to work with the relatively large amount of data as proposed, it is of the outmost importance that the imagery is organised adequately within a dedicated database. The *long-term* objective is to establish a competent knowledge base for the IU and Department of Safeguards.

It should be noted that the four work areas are different in their nature. The Production of "Dossiers" and the General Monitoring work areas deliver analysis results mainly on request from 'customers' within the Agency. The Organisation of Databases and the Reference Information staff are mainly working with internal long term IU management and organisational issues to make the unit as efficient as possible.

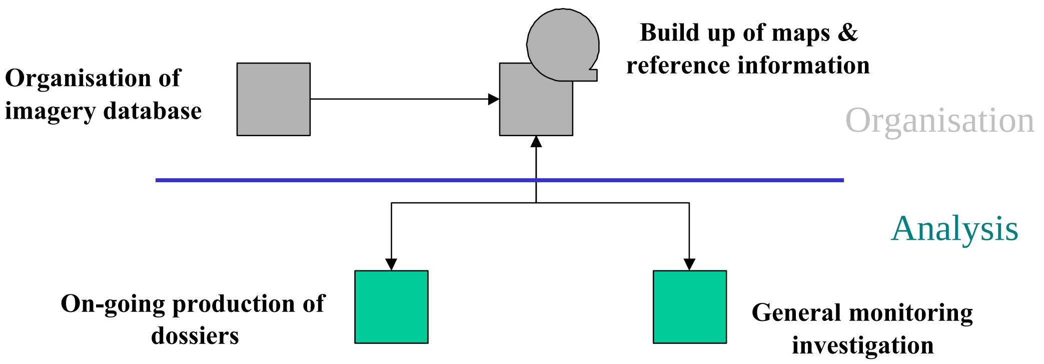

Figure 2. *Work organisation, data flow and main tasks.*

Recommendations

Generally speaking we suggest that the Agency organise the IU so that it will clearly reflect its intended objectives and role.

We recommend the Imagery Unit to be organised within four main work areas. Each work area could be dedicated to one staff member running one of the four main tasks as described above.

As the main budgetary topics and most of the external contacts outside the Agency will be handled by the staff member working with the database, we recommend this position should also be appointed team leader.

Safeguards Applications for the Imagery Unit

Introduction

The Department of Safeguards has specified five potential Safeguards applications using satellite imagery. These applications are oriented either towards a *proactive role* of detection of undeclared activities and subsequent information search, or towards a *reactive role* of verification of known information on specific sites (figure 3). All five applications will benefit from satellite imagery, either by using imagery actively as a principal source of information, or by comparing with other sources as an additional reference. Thus, the two different types of applications call for different work approaches and this should therefore be reflected in the organisation of the Imagery Unit.

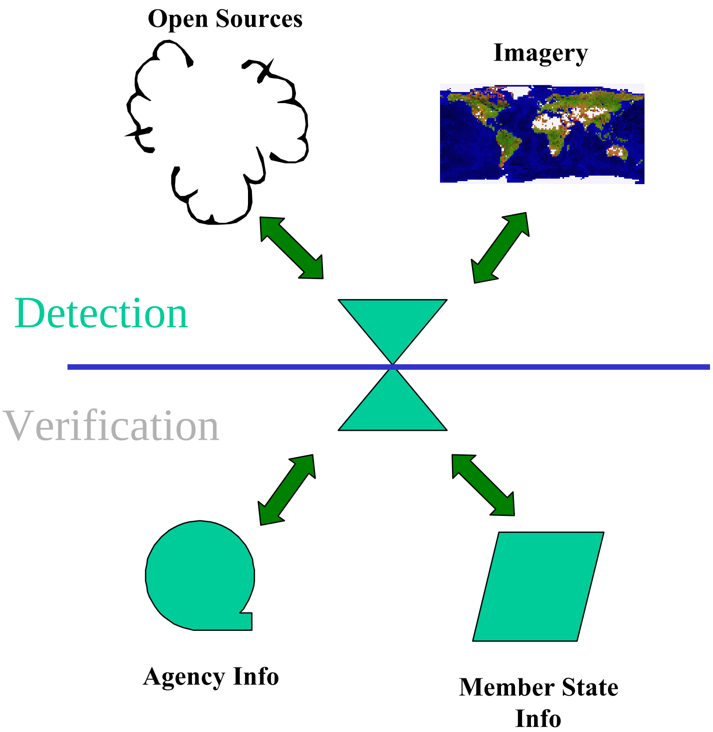

Figure 3. *Two types of Safeguards applications, Detection and Verification.*

Typically the proactive applications should be operated and managed by staff within work area *C General Monitoring* described above. Likewise the reactive applications should be handled either within work area *A Production of Dossiers* or work area *B Reference Information*.

To a very large extent, all the applications as described in this chapter share the most important characteristics as to organisation, workflow, necessary input and other main parameters, while naturally giving rise to specific outputs. These parameters are described in the following.

Use of Imagery as Reference Information - Application 1

The studies of image material for reference purposes will chiefly concern detailed studies and mapping of already localised objects. To this effect, visual interpretation and delineation of digitally enhanced image material will be one commonly used method. Moreover all available drawings, photos, and maps describing the objects of interest will be scanned or digitised and co-registered for merging with satellite data. All reference material will be studied using either GIS processing for computer screen evaluation, or hardcopy for analysis on e.g. light tables or in the field. Various forms of

GIS treatment of the data will be carried out prior to the production of maps and other end results.

GIS interpretation results together with the digitised analogue materials will be routinely filed in dossiers for future reference, necessitating a good system for storing and retrieving information.

Confirmation of Agency Information Application 2

Satellite imagery will also be used to confirm agency-acquired or agency-generated information from other sources by detailed studies of specific areas and objects of interest. For locating these areas where the geographical location is not exactly known, a combination of small-scale and large-scale imagery will be used, while the confirmation of conditions in already localised areas and objects will call for larger-scale imagery.

For this application, digital treatment of the image material followed by intricate measuring of spectral and size features will be needed for the confirmation of declared conditions. These measures, such as size and numbers of buildings or evolving construction activities, should be checked and confirmed against stated data of the Member States.

Change Detection and Monitoring Application 3

Studies of imagery from two or more registration dates (multi-temporal imagery) will enable change detection to be effected. A combination of visual methods and detailed digital measurements will mainly be used for change detection of already localised areas and objects of potential interest. While the study of regional areas will necessitate digital and automated image processing since the amount of data is not feasible to handle only manually.

Hence, this technique can be used in two different ways:

- Change detection to find small modification of a specified and known site.
- Monitoring of large regional areas to detect any significant variety in the terrain that could be classified as a Safeguards issue.

Regular access to new imagery of the same area will make monitoring continuously over time possible. In cases of sensitive areas or objects, or where activities occur rapidly or during a limited time period, updates on a nearly daily to weekly basis could be used to allow detailed monitoring.

It should be noted that due to the high dynamic range in space borne sensor measurements (8 to 11 bits) the change detection method is an extremely sensitive technique for discovering any type of spectral fluctuation on the surface of the earth.

Assessing Open Sources Information Application 4

Assessment of open sources information will also be carried out using imagery, mainly large-scale, to study areas and objects of interest. ‘Objects of interest’ in this case will normally be triggered by news and activities in various open sources such as media, Internet, or other Agency networks.

Digital treatment of the image material will be utilised in combination with visual and digital interpretation of the resulting enhanced imagery. The processing techniques to be used are very much the same as for the Confirmation of Agency Information, however with the important exception that the reference sources of information are very scattered and unreliable.

The result of this application will normally be a decision of either to go further with the issue and include other means, or stop the investigation and conclude that the 'rumours' were false.

Detecting Undeclared Activities Application 5

For detecting undeclared activities and undeclared sites, both relatively small-scale and large-scale imagery will be used, while the detection of undeclared activities at already declared sites will necessitate larger-scale imagery.

For both applications, digital treatment and analysis of the image material will be needed, including various digital pattern recognition techniques. For detecting undeclared sites, both automated and visual methods of interpretation will be used, while the detection of undeclared activities at already declared sites will necessitate visual interpretation, on-screen or on light tables.

Interactions between Safeguards Applications

In reality the different Safeguards applications will interact in an intricate way so that the result from one application may trigger the start of another application. An overview of this is shown in figure 4 below. The application "Use of imagery as reference information" should be seen as a continuous collection and processing of imagery data. The results are stored in a database for future evaluation and comparison. For the application "Confirmation of Agency Information" the first step will be to control if there is any existing information in the database or if an initial preparation has to be performed. If the agency information is confirmed the information is stored in the database for future needs. If the IU finds information that can not be confirmed the proactive applications will be started.

Starting with any one of the proactive applications there will probably be some sort of indication that can be analysed using imagery data (assessing open source information). If the indication can be verified or new questions arise from the image interpretation the next step can be to use multi-temporal data (change detection) and detailed interpretation of high-resolution data (detecting undeclared activities).

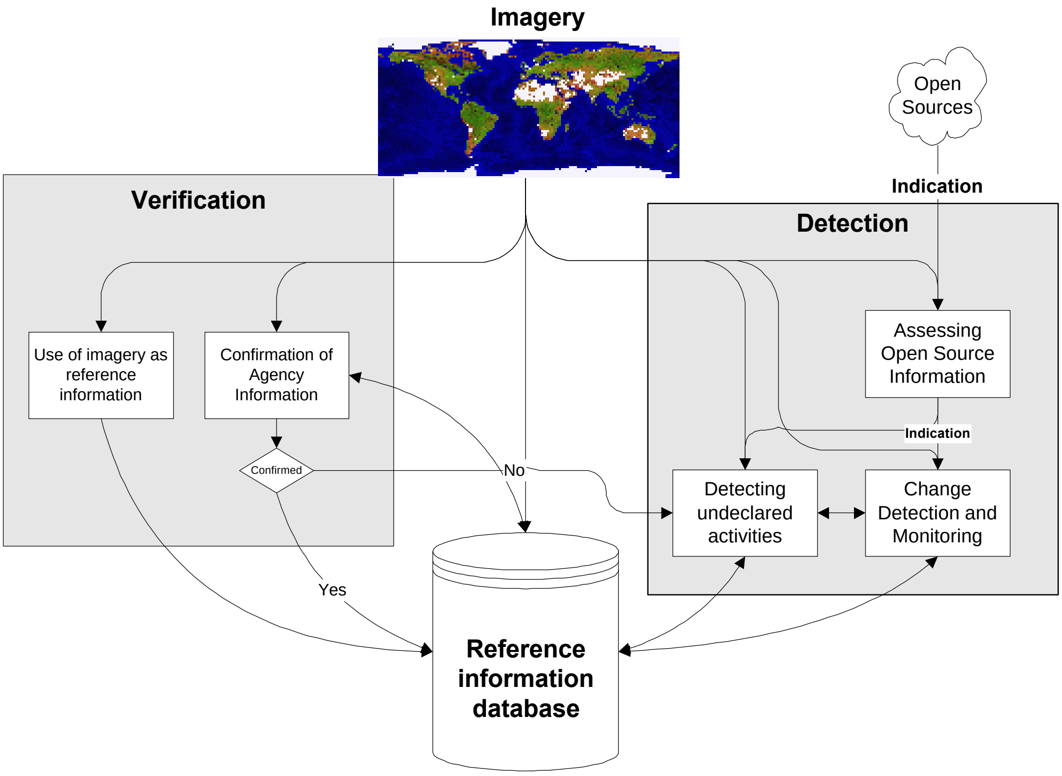

Figure 4. I*nteractions between the five Safeguard applications.*

Recommendation

We believe it is important for the Agency to identify the 'work approach' within each Safeguards applications and especially the interaction and timing between them. This interaction analysis can and should be prepared at an early stage of the implementation, and needs to be tested and finalised during the suggested Pilot Studies.

It is further recommended to start the implementation with the so-called 'verification' applications and expand the number of applications gradually as described in chapter 8. The recommendation is based on the principle of supplying practical, usable feedback to, among others, the inspectors, to begin the learning process as early as possible.

Each specific application area and its battery of required technical image processing and GIS methods should also be carefully defined during the initial Pilot studies. The mix of necessary off-the-shelf purchased, in-house developed or externally created methods and software will be critical for the efficiency of the IU.

Imagery Unit, Workflow Aspect

The following chapter provides a general workflow for the management of satellite data. Thus, the presented workflow can be applied with minor modifications to all five applications of Safeguards. The workflow describes in a simplified way both the various image processing steps and how the imagery data flow is pushed through the Imagery Unit.

Browsing and Purchasing

The different catalogues available from the satellite data providers will be browsed and images ordered. This part of the workflow could be organised in different ways, either performed in full by IAEA personal or as suggested in chapter 6 by agreements with the data providers. That is, transfer the responsibilities for evaluation, selection and pre-processing of at least a part of the regular bulk images to the data distributors.

Georeferencing

The remote sensing imagery will be georeferenced, i.e. made compatible with e.g. national map grids. Depending on the choice of methodology, also this task can be executed either in-house or by the supplier of the satellite imagery. Georeferencing will be performed using ground control points (GCPs) taken from maps or collected during inspection activities using GPS receivers. The imagery should also be furnished with national map grids as well as lat/long markings for maximum versatility.

Data Handling Imagery Database

The georeferenced satellite data and metadata are stored in an imagery database.

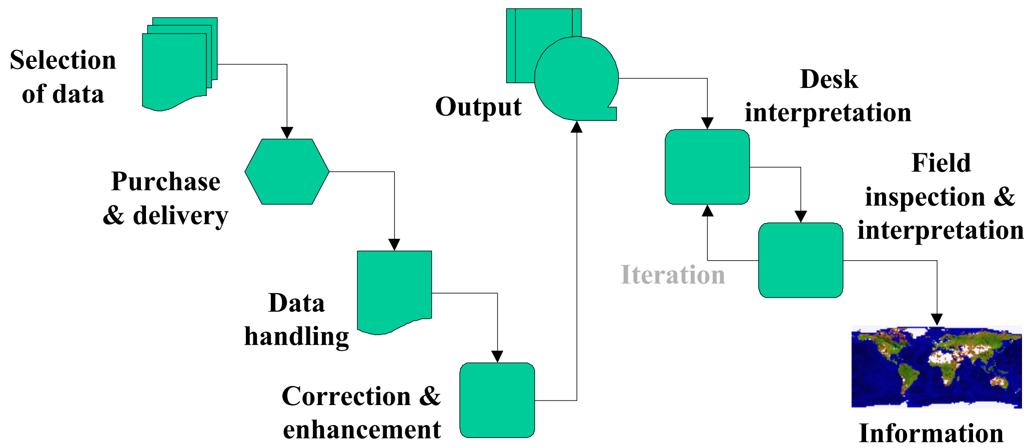

Figure 5. *General Workflow for Safeguard applications.*

Image Enhancement

Digital enhancement of the image material will be needed in order to optimise the interpretation results. The image enhancement will be made both in-house and to a certain degree also by the image vendor. In order for the image enhancement to give optimal results, it is necessary to have knowledge of the objects under study, e.g. Safeguards-related buildings and other structures. It is therefore likely that a skilled Agency operator would obtain better results than an operator, however trained, used to general remote sensing only. For this reason, it is strongly recommended that the digital enhancement, and especially pre-information extraction, will be made in-house by the Imagery Unit.

Image Analysis and Interpretation

After image enhancement, the imagery will be interpreted, utilising ancillary information; e.g. maps and literature for increased interpretation accuracy. The interpretation techniques used will include both radiometric and spatial pattern recognition techniques. One example of the use of radiometric pattern recognition methods is the detection of nuclear reactors in operation through their emissions of hot water from reactor cooling. One example of spatial pattern recognition useful for detecting undeclared activities and sites is the search for a spatial combination of two or more of for example the following features in the vicinity of each other:

- power lines
- security fences
- dams for cooling water/cooling towers
- anti-aircraft guns
- vicinity of water reservoirs, lakes, or rivers
- airfields
- roads
- buildings
- other industrial structures
- other utility structures like camps for staff.

The resulting interpretation overlays will outline the facilities and the individual objects identified, including explanatory texts of the imagery for easy reference. This material will be useful for explaining the interpretation results to e.g. other Agency staff or to Member States.

Small interpretation and presentation scales - 1:50,000 or smaller - will be used for easy overview of groups of facilities or facilities covering larger areas, while larger scales – depending on the availability of imagery - will be used for detailed presentations of individual facilities, groups of objects, or individual objects. Here, scales may vary considerably, going up to 1:1,000 or even larger for the very high resolution imagery used for smaller objects like fences, electric installations or small buildings.

Field Inspection and Interpretation

The material resulting from the work will consist of imagery, imagery interpretations, digital database entries and documentation of the type found in the dossiers already used by the Agency today. The material will be stored in analogue as well as digital format. The digital images, interpretation overlays, and digital database entries will be copied onto rugged laptop computers. This will allow access to easy reference also out-of-office under severe field conditions. One example of such field use is the quick measurement of the area of a building complex during inspection activities. Analogue material (e.g. hardcopy photos with interpretation overlays) will naturally also be brought into the field.

Benefiting from the data and knowledge gained as described above, image interpretation will be a routine tool in preparing for, facilitating the execution of, and evaluating the result of inspections. Following the procedures described above, the envisaged workflow will comprise:

- Pre-inspection image interpretation of mainly large-scale imagery aimed at corroborating ancillary data, locating previously unknown areas/objects of interest and familiarising the Inspector with the inspection site
- Use of image material during inspection work, using large-scale imagery with overlays depicting the results from the image interpretation, for orientation purposes as well as for comparison of the findings with those of the pre-inspection image interpretation
- Post-inspection image interpretation, evaluation of the inspection results and evaluation of the techniques used.

Depending on the results the process stops here or a new loop of field-inspections starts.

Data Handling Reference Database

All new interpretation results, including notes and photos from the field, and other available digital information, are stored in a geographical database containing all the earlier reference information of the case.

Recommendation

Whatever size and organisation the Agency finally decides upon for the Imagery Unit, we strongly recommend that a core of interpretation staff and system is maintained. A competent digital enhancement and interpretation team with in-house developed software will be the most valuable part of the Imagery Unit. It is within this core, in co-operation with field inspectors, that the Agency can build up a unique knowledge and experience.

Imagery Unit, Input/Output Aspect

The following description presents in condensed form the needed resources and the resulting outcome of the Imagery Unit. It gives the Agency a first tentative understanding of the resources needed (input) and the potential outcome from the IU (output).

Input

Personnel

The following capacities need to be present in or around the group of people dealing with image interpretation and related activities:

- Knowledge of the Agency's field of activity
- Image acquisition skills (locating, assessing usefulness and purchasing of remote sensing imagery)
- Image processing skills (georeferencing, image enhancement)
- Image interpretation skills (visual and digital)

- GIS skills (use of digital geographical databases, projection systems etc.)
- Database management (logistic support, archiving and distribution of geographical data)

Hardware

- Image treatment systems
- Computers and LAN for database management
- Light table(s)
- Digitising table/tablets
- Colour printer(s) for imagery and overlay output

Software

- Image processing and interpretation software
- GIS software
- Database software

Data and Information

- Imagery (medium to high resolution)
- Maps and sketches from field (for reference as well as for georeferencing of imagery)
- Literature (for reference)

Output

The output from the image interpretation and image interpretation-related activities will comprise:

- A reference GIS digital and hardcopy imagery database consisting of georeferenced data on interpreted facilities and objects with interpretation overlays for easy comparison with imagery from other dates or with other data sources.
- Various information prepared to be the foundation for further decision making by the Agency; confirmation or refutation of Agency-acquired or Agency-generated information; change detection and continuous monitoring; assessments of the credibility of information emanating from open sources; detection of undeclared activities and undeclared sites.
- Increased efficiency of the inspection work.

Imagery Unit, a Fictitious Case Study

The fictitious case study below gives the reader some sense of how an IU might work during a concrete event.

Introduction

Over the past few months, stories have been printed in a number of international newspapers, journals, and magazines carrying the information that, over the last two years, Alphaland is suspected to have built a sizeable nuclear development site somewhere in its northern provinces. Parts of the site are said to be located underground. Dependable sources give a sparsely inhabited and poorly developed 30 x 30 km area around Alphaville, the small county capital, as the most likely location of the site, but some sources give the vicinity of another even smaller town about 100 km to the north of Alphaville as the probable location of the site. The Agency wishes to corroborate the substance, if any, of this information about a nuclear development site without undue delay.

The Agency image database is checked for any related information. Neither image material nor any other data on any kind of nuclear development site in the area exists in the Agency database. A few maps and some literature over the area are found in the Agency library, but no signs of developments corroborating the information are found.

Selection of Data

The availability of already existing image material is checked with the vendors of satellite data. From this search, it transpires that various satellites have sporadically covered the area since the early 1970s. The image availability over the area increased markedly over the past five years, with several registrations per year from various sensors being available. Of the available imagery, the most recent image material of suitable quality is (spatial resolution and date of last acquisition in brackets):

- Radarsat imagery (8 m, May 1998), example in (figure 7).
- SPOT image (20 m colour and 10 m black-and-white, January 1999), example in (figure 6).
- Landsat TM image (30 m, April 1998, image has some clouds. This image also covers the alternative location of the nuclear development site as described above), example in (figure 8).

The SPOT black-and-white image is chosen because of its being most recent as well as having the highest spatial resolution of the available image material. An order is placed for this image with a data supplier. The Landsat image is also ordered due to its coverage of the suspected alternative location of the nuclear development site as well as for providing comparison material with the more recent SPOT registration.

National topographical Alphaland maps well as Soviet military maps from the 1970s over the area are ordered from well-stocked map shops, while literature on the geology, vegetation and agriculture of the area is ordered from bookstores in England and the US.

Delivery

Both images are received from the vendors over high-speed communication equipment within forty-eight hours of placing the orders.

The maps and literature start to arrive about three days after placing the orders, the last items taking several weeks to arrive.

Precision Correction

The images are geometrically corrected to the Alphaland national map grid at the Agency. Since the site is previously unknown to the Agency, no GPS ground control points are available for correction. Instead, the geocorrection is done using easily identifiable points on the maps, e.g. road junctions, bridges, and river bends. The precision takes one day for a preliminary version to be made, and subsequent work is done using the resulting product. Upon the delivery of a batch of Soviet military maps with a high degree of precision a week later, the precision correction is reiterated resulting in a higher degree of precision in the result.

Enhancement

The imagery is digitally enhanced for maximum readability. This is done using standard image treatment software, taking only hours to complete.

Image Interpretation

The images are interpreted using both digital and visual image interpretation. Digital methods are i.a. used to detect areas lighter than adjoining areas, possibly indicating disturbed soil and/or large building complexes. Visual methods are used to check on the areas found during the digital analysis. Such visual methods include looking for roads, light patches indicating possible construction activities and other signs of development unusual in this little-developed region. Frequent comparisons are made with the available maps and literature.

About 20 km north-east of Alphaville and close to a small village, an area is detected displaying a degree of industrial activity unusual for the area. No other area displaying any kind of unusual features is found in any of the images.

Intensified image interpretation of the 10 m resolution SPOT image from January 1999 leads to the identification of the following features in the image:

- A 200 x 300 m very bright spot indicating disturbed soil, possibly a dumping site for material from underground excavations
- Two large building complexes, each about 500 x 500 m and containing large buildings. Both the size of the building complexes and the size of the individual buildings within the complexes are significantly larger than those found elsewhere in the region
- A one-runway airfield, probably with a paved concrete surface, with a 1,200 m runway.
- A nearby river with a width of about 40 m. Due to the lack of thermal infra-red capacity of the SPOT satellite, no information is available as to the temperature of the water in the river upstream and downstream from the suspected site (indicating outlet of cooling water from a nuclear facility).
- Comparison with the Landsat TM image from May 1998 shows that, of the above-mentioned features on the suspected site, only the airfield and a small area showing signs of buildings were present. As far as can be seen on this less detailed image, the runway length at the time was only about 800 m. In spite of the availability of thermal infrared information, no indication of e.g. hot water discharge in the river is found in the image.

The features identified in the two images are marked on overlays and digitised.

Conclusions and Follow-up

From the information gathered, it seems that there is a strong possibility that Alphaland is constructing, or has constructed, a nuclear development site. If so, much of the work has been carried out between May 1998 and January 1999. However, it is not possible to determine with any degree of certainty the type of site.

On the strength of the information gathered, Alphaland is invited to submit information to the Agency regarding the suspected site. At the same time, the Agency orders high-resolution satellite image registrations from two satellite operators to be made over the area. Two orders are placed in order to increase the possibility of successful registrations in spite of the weather in the area, which is often cloudy. Regardless of whether the Alphaland authorities will submit any information on the site or not, the Agency will therefore in all probability have a much more detailed picture of the situation at the suspected site within a few months' time, enabling further actions to be considered and taken.

Imagery Examples

Examples of the mentioned satellite imagery are shown in (figure 6-10). The examples have no connection to the fictitious case study.

Figure 6. *Central Stockholm registered by SPOT . The image is a composite of panchromatic and multispectral data. © Satellus AB.*

Figure 7. *RADARSAT data, Fine Beam Mode sample. Roads and other infrastructure are easily distinguishable. ©Canadian Space Agency/Agence spatiale canadienne.*

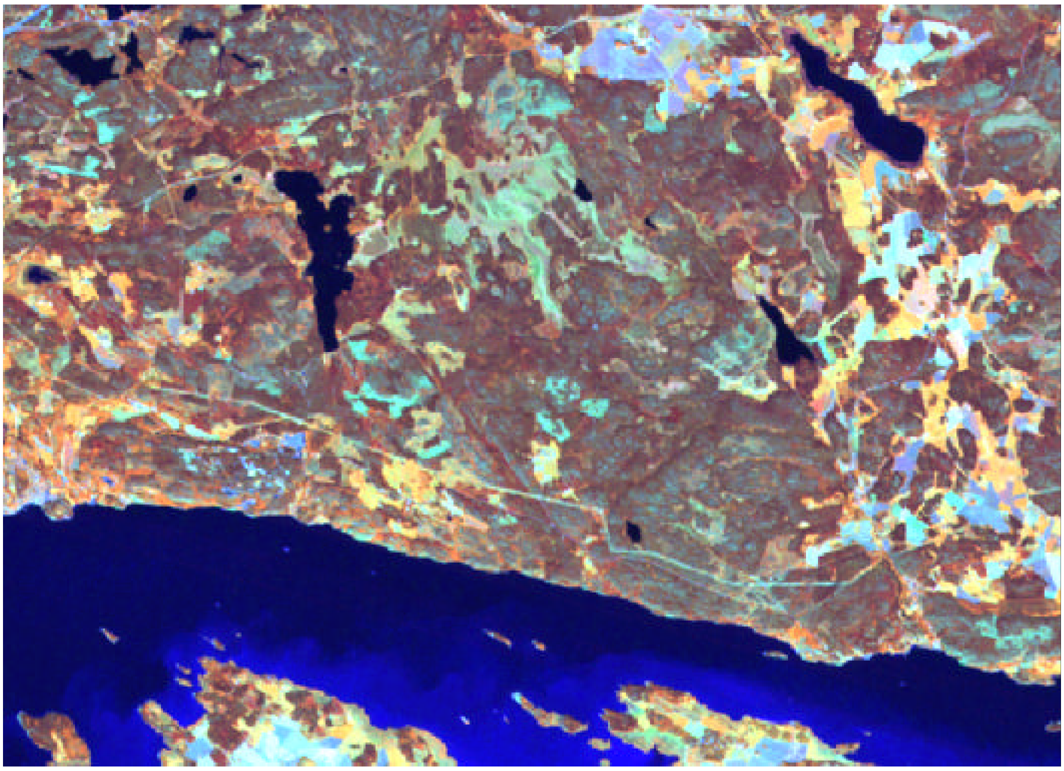

Figure 8. *Landsat TM band 4, 5, 3 (RGB) with a resolution of 30 metres. New roads and clearcuttings are visible. © Satellus AB.*

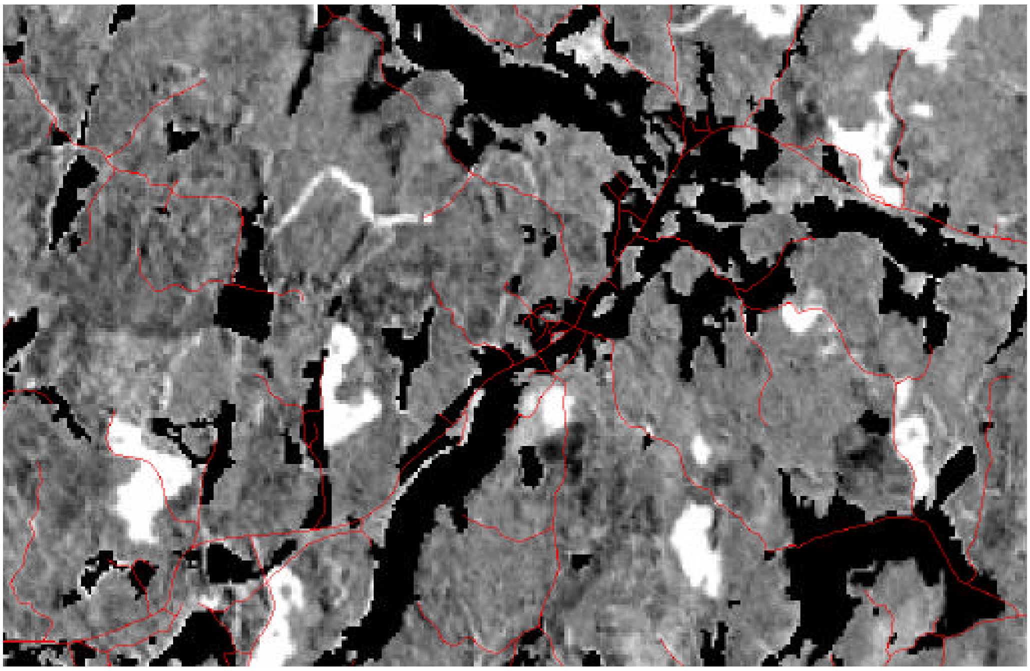

Figure 9. *Change detection image (between year 1989 1995) within forest areas using the Landsat TM sensor. Indicated bright areas are forest clear cuts and also a new road track can be seen. The existing road network as represented in a ordinary paper map is outlined in red. Black areas are non-forested areas (e. g. agriculture land, water). © Satellus AB.*

Figure 10. *Example of data from IKONOS (panchromatic, 1 meter resolution, registered October 22, 1999) showing Beijing. © Space Imaging*

Recommendations

During the implementation, we recommend that the Imagery Unit will be evaluated and measured by several means and methods. The techniques described above: volumes and times of processing flow, input/output-ratio in the form of cost and benefit and experiences from concrete case studies, are the three most important evaluation methods.

The evaluation should be performed on a regular basis and, thus, give specific guidelines for the next implementation phase.

One key parameter in the creation of an Imagery Unit will be the ability of the Agency to integrate the software, hardware and associated equipment into a well tuned processing unit. It is recommended that the Agency carefully specify and evaluate the integration and 'hand-shaking' between the various off-the-shelf sub-systems.

Staff and Competence Development

Introduction

During the process towards an integrated operational structure for the Imaging Unit, there are a number of opportunities and reference points that need be highlighted to ensure that they are fully exploited.

In terms of building competence it is clear that formal courses will have an important role in ensuring that the IU possesses the skills that can be expected of it. In addition to this, informal on-the-job training will have a significant role in building competence. In order to make the best use of both forms of training, it is important to schedule feedback sessions where experiences are discussed and documented as an input to potential modifications and future developments.

We foresee the following recruitment and training needs.

Recruitment of Operators

The recruitment of proficient operators is vital to the success of the programme. The operators selected must (in some cases after complementary training) possess:

- Knowledge of the Agency's field of activity
- Image acquisition skills (locating, assessing usefulness and purchasing of remote sensing imagery)
- Image treatment skills (georeferencing, image enhancement)
- Image interpretation skills (visual and digital)
- GIS skills
- Database management skills.

Preferably the background of the operators should be from an operational, application oriented image/GIS processing environment, and it will be more important to have a solid knowledge from production of intelligence support rather than remote sensing research qualifications. This is especially significant for the positions working with production of 'dossiers' and reference map information.

If possible, the operators selected should also have additional language capability, especially in languages of countries/areas where the Agency often conducts inspections.

Training

Training of Inspectors

There is a need for a general understanding of the remote sensing technology among inspectors, especially as we foresee mutual operations including staff both from the Imagery Unit and from field inspectors. These inspectors should be selected and trained to understand the possibilities and constraints of the image interpretation techniques used. This training will include:

- general remote sensing (including map-reading, background in physics and related subjects and exposure to different sensors and types of data)
- visual remote sensing exercises aimed at developing an ability to use the techniques
- digital remote sensing exercises aiming at understanding the techniques
- GIS and database management

The training will be distributed over approximately a year and integrated with pilot studies and ordinary work. It is estimated that a three-week course would be sufficient to meet these needs.

Training of Operators

The recruited operators (including database management staff) should also be trained to understand the structure and scope of the inspectors' work. The training will comprise:

- Agency history
- Agency and Safeguards objectives
- Organisational development trends
- Nuclear cycle (including chemical and physical background)
- Hands-on exercises in the actual tasks performed by the inspectors.

It is estimated that this training will take three weeks.

Joint Training of Interpretation Working Groups

After the inspectors and the operators have been trained as outlined above, it will also be necessary to train them together in order to create interpretation ‘working groups’ consisting of both inspectors and operators. This training will be geared towards practical exercises, including all activities envisaged to constitute part of the work of the interpretation teams, i.e.

- Creating and using reference information
- Confirmation of or giving added credibility to Agency-acquired or Agency-generated information
- Change detection and on-going monitoring
- Assessing open sources information available to the Agency
- Detecting undeclared activities and undeclared sites,
  and inspection-related activities
- Pre-inspection image interpretation aimed at corroboration of ancillary data or location of previously unknown areas/objects of interest
- Use of image material during inspection
- Post-visit image interpretation and evaluation.

The training will be distributed over approximately two years and integrated with pilot studies and ordinary work. It is anticipated that this training will take five weeks.

This training is furthermore meaningful for creating good relations between operators and inspectors, and a mutual understanding of each other's working conditions.

Capacity Issues

The working groups executing satellite based Safeguards will preferably be composed of both inspectors and Imagery Unit operators. It is important that the groups are large enough to enable them to function also during periods of staff absence due to e.g. travels or illness. For this reason, a certain over-capacity must be built into the system. How this will be done depends largely on the organisational format chosen by the Agency, and no recommendation is therefore given. However, even if it is theoretically possible for one person to possess all the abilities listed above as necessary for the operators to possess, it is unlikely that they will all be united in one person. Instead, it is likely that it will take a minimum of at least three persons to fulfil all the Imagery Unit abilities listed above. However, with more than three persons, there would also be a certain over-capacity, both in terms of competencies and of the workload. Three operators are therefore suggested as an absolute minimum number.

The number of inspectors taking part in the pilot studies must be large enough to ensure continuity in the eventuality of staff leaving the Agency before the skills and experiences gained during the pilot studies can be fully drawn upon in preparation for the start of full-scale operations. In order to reach this goal, a minimum of five inspectors should be selected for training.

Recommendations

The skills and competence of the staff within the IU will be a key issue for the Agency. It is therefore recommended that a long-term recruitment and training plan is formulated early during the implementation.

We strongly believe that joint working groups, including both inspectors and IU operators, will benefit the optimal use of satellite based imagery. It is therefore suggested that the work procedures and other relations are clarified during the implementation. One tool with which to do this is the suggested mutual training courses.

Imagery and Security issues

Imagery

Introduction

Commercially available satellite data has emerged as a potential complementary open information source to support IAEA's traditional and extended Safeguard activities. Currently there is a rapid development of techniques and methodologies based on data from remote sensing satellites, image processing, GIS and overall information technology supporting assessment and monitoring of objects and activities on the earth's surface. Many of these successful methods are based on multi-sensor concepts exploiting data from different satellite sensors and thus utilising the advantages of different physical capabilities.

Monitoring projects can today be performed in a way that combines low-, medium- and high-resolution satellite data. Depending on the rate of changes and the size of the studied objects the monitoring can be designed in a way to optimise the quality of the end product and the total economic efficiency.

Imagery Market and Advantages

In the coming five years a fast growth of the remote sensing market is foreseen with satellite operators offering data from a number of new passive and active sensors of interest within IAEA's Safeguard activities. The increased offers and supply of satellite data on the market will make the use of satellite data more favourable and effective.

Following the success of launching the first civilian satellite capable of acquiring high-resolution imagery IKONOS in September this year, it is very probable that several such systems will become operational during 1999 and 2000. These satellites will provide imagery with a spatial resolution of better than 1 metre under normal commercial terms and conditions. By 2001 up to four such satellites are expected to be in operation from three different commercial operators.

Imagery with equivalent characteristics has been assessed by the Agency and has a clear potential to act as a complementary source of information within the Safeguards program. The growing number of commercial operators that plan to offer such imagery will probably lead to price reductions so that this information source will become progressively more attractive.

The current development will give the following advantages for IAEA and the proposed Imagery Unit:

- Prices of satellite data are expected to fall due to the greater competition among satellite operators and data vendors. The new US initiative to radically drop prices of Landsat data is a first step in this process.
- The probability of obtaining useful registrations covering a selected object within a given time frame will be larger since more sensors will be operative and receiving data from the earth's surface.

- It will become easier to acquire an optimal satellite data coverage of a selected object, since some satellite imagery vendors will be capable of offering full service data agreements meeting the requirements for multi-sensor supply of data from the clients.

It is important that experiences gained from the use of current satellite data sensors and aircraft surveillance imagery for inspection, planning, site identification and in supplementing other information sources will be transferred to and utilised by the IU in its use of high-resolution satellite imagery.

Full Service Data Supply System (DSS)

Focusing the work of the IU towards application-oriented digital processing and interpretation for decision support will result in requirements for comprehensive pre-processing to be performed by the satellite data suppliers.

The introduction of a so called full service Data Supply System (DSS) where the image supplier(s) take the responsibility for and the risks in creating and delivering the best cloud-free coverage of a chosen facility, would be the basis for effective imagery purchasing work at the IU.

The suggested DSS is proposed to consist of the following components:

- Planning and preparation of image acquisition of data from different sensors according to requirements specified by IU. This task covers among others the continuous contacts the technical staff will have with the different satellite operators.
- Programming of satellites to achieve required coverage of selected facilities and areas of interest. Continuous monitoring and fine tuning of registration results.
- Establishment and continuous updating of an Image Catalogue (IC), based on an Internet solution. The catalogue should consist of geo-referenced quick-looks from the different satellite sensors.
- Geometrical and radiometric correction of selected scenes according to a predefined schedule as agreed between the IU and the supplier.
- Establishment and continuous updating of an Information Database (ID) presenting information for the IU regarding the status of different production steps and estimated delivery dates of the different data sets.
- Delivery of data to the IU by several media such as Internet, courier, mail, or other Agency dedicated links. The choice of data transferring method should be adjusted to the needed delivery time and security precautions.
- Technical support regarding image acquisition and pre-processing of the satellite imagery.

Objectives of the DSS

The objective of the DSS is to create a co-ordinated approach for supply and pre-processing of satellite data to serve the IU with the best accessible data for further processing and evaluation. The aim is to have access to all satellite sensors at the best market price together with an effective technical support from the image providers. In this concept the management of bulk data acquisition, data pre-processing and corresponding technical support is outsourced preferably to a few suppliers acting as focal points to the IU. The co-ordinated DSS approach will give the following advantages for the IU:

- Acquisition of satellite data at the best prices. Prices can be pushed down due to large size order.
- Co-ordination of an operational multi-sensor approach becomes easier.
- Acquisition of auxiliary data for geometrical correction such as GCPs and DEMs will be streamlined.
- Image acquisition in a multi-sensor concept will be performed in an effective way. The concept will allow a systematic and effective monitoring of registration results and quality control of raw data from the different satellite sensors.
- Consistent quality control of data from different sensors.
- IU can focus on its prime objectives within the Safeguards program and the administrative work for data reception and pre-processing is minimised, since IU only has to deal with a few focal points responsible for the complete DSS.

It should be noted that the recommendations regarding IU organisation and size of the staff (chap. 4 and 5) and the cost calculations (chap. 10) are based on the DSS concept and outsourcing of acquisition and pre-processing functions to some degree.

Security Issues

Elimination of Negative Manipulation of Satellite Imagery

To meet the objectives of the utilisation of satellite data in the Safeguards program it is of crucial importance that the data used in the process is not manipulated in a way that destroys the information content required by IAEA/IU.

In general all processing of satellite data is a form of intentional and positive manipulation in order to achieve a usable product meeting the user requirements. The processing of the satellite data is usually performed as follows:

- Geometrical correction of the satellite data where the raw data is geometrically rectified to correspond to a map projection and reference ellipsoid chosen by the customer.
- Radiometric correction is performed to improve the information content of the satellite data to fit the requirements of the intended use of the satellite e.g. visual interpretation and digital classification. The images are usually radiometrically corrected by the application of calibration coefficients to the individual detector in the satellite sensor. Also usually any residual striping in the data is suppressed by filtering and by statistical methods.

When implementing satellite imagery within an IU supporting the Safeguards program the possibilities for negative manipulation of the satellite data in contradiction to the purpose of the IAEA have to be identified and eliminated in order to meet the overall objectives. At this stage the following forms of negative manipulation can be identified:

- Radiometric manipulation where the spectral signature for individual or groups of pixels are changed or replaced in order to eliminate certain objects from the satellite data.
- Geometric manipulation where the correct position of objects are changed.
- Temporal manipulation where the correct acquisition date is changed in order to hide the situation on a given acquisition day.

The risk for the above mentioned negative manipulations can be eliminated by the application of a control system where the delivered data and the performed processing are checked. The control system can consist of the following components:

- Control performed in parallel data sets from another satellite sensor, selected and supplied on a sample basis with reference to the original data sets. This parallel data should also be supplied from another provider and producer. By this control step all the above mentioned negative manipulations could be checked and discovered. This step will increase the cost for data dependent on the chosen sample scheme.
- Control of reprocessed raw satellite data, on a sample basis, with reference to the original data sets. The control is to be performed as unannounced inspections at the production site of the original data, by personnel from the IU responsible for the control. With this control step the satellite data itself together with the production process will be checked and verified.
- The data provider and processing organisation has to perform the work in accordance with a recognised certification system where the processing will be performed in a way that the security requirements from the Safeguards will be met.

The control system has to be integrated with the supply of the satellite data and designed, negotiated and agreed upon parallel with the contracts for the supply of the satellite data.

Confidentiality in Image Coverage

The supply of satellite data has to be made in a way that the requirements regarding confidentiality of the satellite data used in the extended Safeguards can be met.

To meet the objectives of the extended Safeguards it is important that information about the location of scenes and objects studied will be strictly confidential. No information whatsoever about scenes purchased and used within the Safeguards program is to be made available to a third party.

A supplier of satellite data and processing services has to apply a certified production system including a certified security system. The following components are of importance in such a system:

- Personnel involved in any part of the production and processing of products for Safeguards have to be security checked and meet the security requirements.
- Only a limited number of persons at the provider’s facility are to have knowledge of IU as end user of the products and the extracted information.

- Value added processing of satellite data has to be performed in facilities equipped with necessary security equipment to avoid any possibilities for a third party to get access to any confidential information.

In addition to the implemented certified security system, unannounced inspections at the production site are to be performed. At these inspections the routines for confidentiality together with the risk for negative manipulation are to be studied and evaluated.

Recommendations

The preliminary requirements for a DSS have to be formulated on the basis of the IU objectives and planned activities. Furthermore, to gain valuable experience in the multi-sensor concept regarding acquisition and pre-processing, the DSS should be tested on a pilot scale.

A few DSS suppliers are to be selected by the IU in an open tender. Based on the final requirements formulated after evaluation of the performed DSS test, a request for quotation is to be sent out to a shortlist of potential DSS providers.

Based on a security strategy for the IU, a control system for negative manipulation and confidentiality has to be defined. The security requirements will be integrated into the general requirements for the DSS.

Equipment, Data storage and Localities

Introduction

This chapter describes the equipment needed to perform the work and handle the data described in the other chapters of this report. The focus has been set towards small, efficient and interpretation-oriented Imagery Units within the Department of Safeguards. The equipment described here corresponds to the ambition level described as Phase 1 in chapter 10 “Cost Simulation”. All five proposed applications can be handled and the Imagery Unit will work with approximately 145 activities and purchase about 240 images each year. If the ambition level is changed to a Reduced or an Enlarged activity scenario the equipment will be slightly different (changed number of PCs and SW licences).

The concept is aimed towards an expandable equipment environment, either by adding new equipment that is easily integrated with the existing equipment, or by developing the existing equipment (particularly software) towards a more task-focused user interface that is designed for the special needs of the Safeguards work. Chapter 7.4 (Future Development) describes different options that either could be included in the start of the work or added in the future. These options are intended to make the software more adapted to the work to be performed (user friendly), hence making the work more efficient. It could also deal with the handling and storing of data in a more efficient and searchable manner.

Necessary Equipment for Safeguard Applications

The different Safeguards applications for which satellite imagery can be used are:

1. As reference information
2. As confirmation of Agency-acquired or -generated information
3. Change detection and on-going monitoring
4. Assessing open source information available to the Agency
5. Detecting undeclared activities and undeclared sites

Besides these ‘in-house’ office applications we also include in this description essential equipment for inspection fieldwork (the field visit part). The equipment needed for application 1 - 5 is the same and described in chapter 7.2.1. Equipment required for fieldwork is described in chapter 7.2.2.

In-House Equipment

Hardware

- PC – Windows NT, 21” screen
- Colour and b/w laser printer (A4: 210*297 mm)
- Colour printer, minimum A4 printing size, photo quality

- Ink-jet plotter, minimum A0, 300 dpi
- Scanner, minimum A4
- CD-ROM writer/reader
- Large data storage media.
- Digitising table, recommended A0 size (primarily for digitising maps not available in digital format)

Software

- Advanced satellite image processing software, including coordinate handling with the possibility of integrating vector information. Should allow development by user.
- Advanced image processing software, specialised towards enhancing image raster data.
- Advanced geographical vector data processing software, including coordinate handling with the possibility of integrating raster information. Should allow development by user.
- Simple database for storing metadata concerning geographical data (raster and vector) and media archive.
- "Office" software, such as word processing and calculation.

Other Equipment

- Light table, minimum A3 size (small "box", easily moved when not used)
- Stereo-viewing instrument
- Physical archive for different types of data

Fieldwork Equipment

Hardware

- Portable PC with CD-ROM reader
- Field digitising table

Software

- Vector data processing software, including coordinate handling with the possibility of integrating raster information with simple image enhancement for display purposes. Should allow development by user.
- "Office" software, such as word processing and calculation.

Description

The equipment described below is tailored for a team of four operators, Safeguard inspector excluded (Phase 1 scenario). It is assumed that the equipment will be installed in a “normal” office environment, and that ordinary technical support, back-up routines, basic database management support, PCs network infrastructure, and other facilities will be supported by a support department of the Agency.

If more than one Imagery Unit will exist within IAEA, the equipment listed below should be multiplied with the total number of Imagery Units. Each Imagery Unit is viewed as a unique group and does therefore have all the equipment needed to perform the work and can thereby be physically and administratively separated from the other Imagery Units. There is however the option of allowing the Imagery Units to co-operate, hence sharing some of the equipment listed below. This primarily concerns plotters/printers, scanners, data storage media, databases and the equipment listed in the “Other equipment” chapters, except for fieldwork equipment.

Hardware

The hardware equipment has been defined to meet the requirements of the Phase 1 activity scenario, but also to be easily expandable for future needs. The capacity of the hardware should well match the software used on the system as well as the amount and size of data handled. It should also allow increased amounts of data and/or software within a realistic perspective for future needs.

Each Imagery Unit is here based on three high-capacity PCs connected to a fast Intranet. The reasons for selecting PCs and not workstations are not only that PCs today have a capacity that well matches the needs for the tasks involved in the Safeguards work, but also that several software needed are only available for PCs.

The choice of output units are dependent on the required print quality, but one photo-quality A4 plotter and one ink-jet A0 plotter are suggested. An A0 digitising table and an A4 scanner are also included in this listing. As storage media we propose to use CD-writables for storing ongoing work and dossiers, and a large capacity storage system.

(Figure 11) gives an overview of how the hardware preferably should be connected within the Department of Safeguards. For cost effectiveness, some equipment such as the mass storage database (described in chapter 7.3.4 “Optional Equipment”) and most of the output devices could be shared between the different Imagery Units. It is however possible to have a unique set of this equipment within each Imagery Unit.

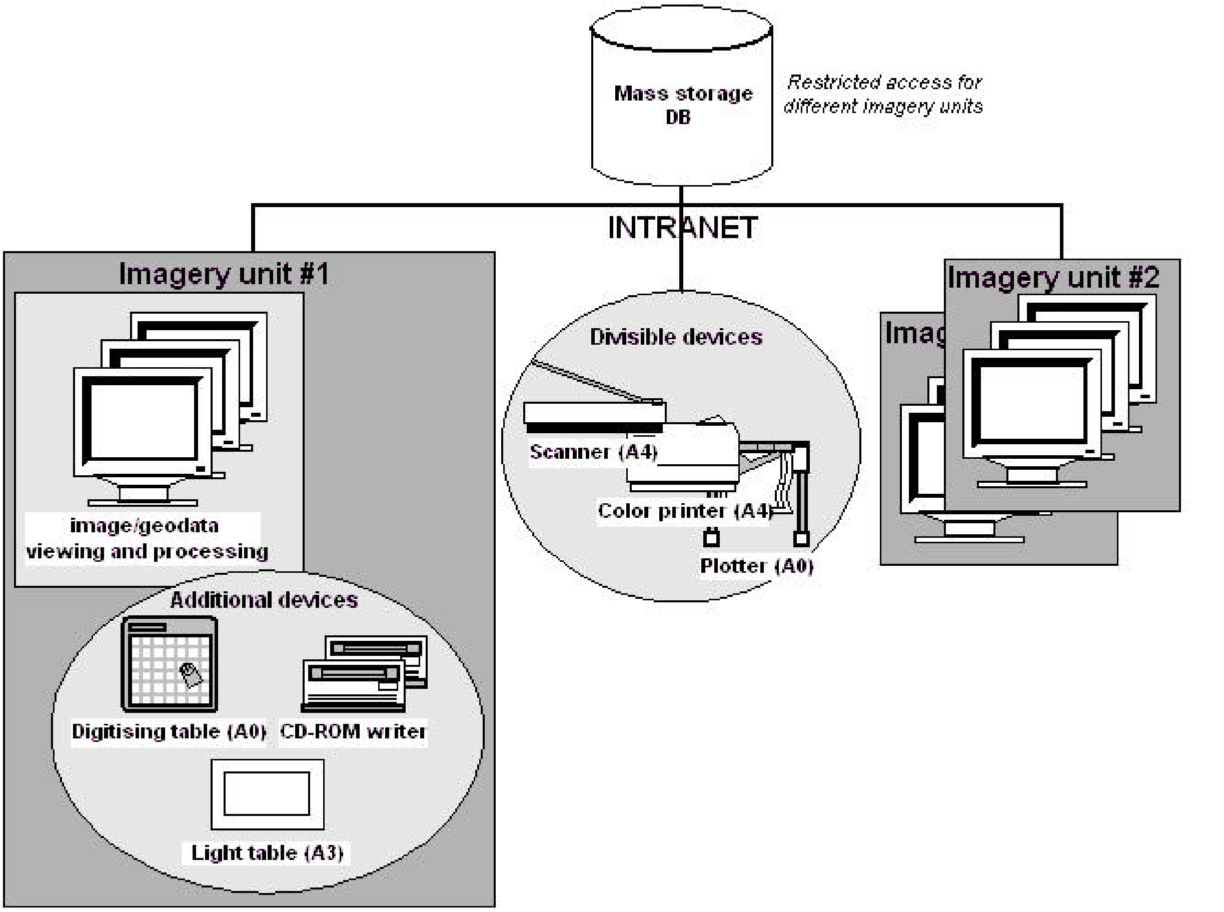

Figure 11. *Overview of the hardware connections for the Imagery Units.*

Table 3: *List of necessary hardware*

Hardware	#	Comments
At office		
Hardware		Pre-request: switched Ethernet, 100 Mbit
PC	3	500 MHz Pentium, 512 Mb RAM, 8G hard drive, 4 MB videoram, 24 speed CD-ROM drive, 100 Mbit Ethernet. Preferably Windows NT.
21" screen	3	
Digitising table (A0: 840*1200 mm)	1	Primarily for digitising geographical analogue data not available in digital format, such as old maps.
Colour printer, photo-quality A4: 210*297 mm	1	E.g. Kodak XLS 8600 PS (photo-quality)
Colour and b/w laser printer A4: 210*297 mm	1	E.g. HP 2000C/2000CN Series
Ink-jet plotter, 300 dpi A0: 840*1200 mm	1	E.g. HP Design Jet 755/PS
Scanner, A4: 210*297 mm	1	600 dpi
CD-ROM writer	2	
Large capacity storage (GB Disk)	1	400 GB disk. Different techniques, specified cost are USD/GB hard disk.
In field		
Portable PC	*	*One for each Safeguard inspector. CD-ROM reader, 300 MHz, 64/256 MB RAM, 1024x716 resolution, 4.3 GB hard disk drive, operating system Windows 95/98 or Windows NT 4.0. E.g. IBM Thinkpad 1451.

Software

The software has been defined, as well as the hardware, based on the criteria of performing the necessary tasks for the different Safeguards applications with good capacity, but also to be easily expandable for future needs. It should also allow increased amounts of work within a realistic perspective for the future.

The focus has been set towards well-established and functioning software that can also easily be adapted towards more task-oriented interfaces and procedures.

Even though satellite data in itself is raster data, it is essential that vector data handling is included within the software capacity. Other geographical reference data could be stored in vector format and there may also be a need to digitise features interpreted from the satellite images. It is also of the greatest importance that the different software can handle the same data formats, so that data can be transferred easily between the software.

Preferably, metadata about the geographical data should be registered in a database as well as information concerning the media archive. Even though the data itself is not stored in a database (see chapter 7.3.4 “Optional Equipment”), metadata should be registered from the very beginning, hence allowing fast and easy search for data and a quality check of the data used for the different Safeguard applications. Metadata contains information about the data itself and could contain information such as:

- Identification information
- Quality and source information
- Geometric description of data
- Geographical coordinate system
- Properties and attributes
- Information concerning distribution
- Processing history

Table 4: *List of necessary software*

Software	#	Software example	Comments
At office			
Very advanced remote sensing software for handling satellite data with geographical coordinates, including some vector functionality. Should allow development by user.	1	ERDAS Imagine Professional	The cost for other remote sensing SW such as ER Mapper and PCI EASI/PACE is about the same.
Simple remote sensing software for handling satellite data with geographical coordinates, including some vector functionality. Should allow development by user.	2	Erdas Imagine Essentials	Other comparable products are Image Analyst (optional module for ArcView GIS) and PCI Imageworks.
Very advanced image processing software, specialised towards enhancing image raster data.	2	Photoshop	
Advanced geographical vector data processing software, including coordinate handling with possibility of integrating raster information. Should allow development by user.	2	ArcView GIS	The cost for other SW such as MapInfo is about the same.
Web browser	3	Netscape Navigator or MS Explorer	
Simple database for media archive and metadata information	1	MS Access	One database, but all operators should have easy access to the database.
Ordinary office software (word processing, calculation)	3	MS Word, MS Excel.	
In field			
Advanced geographical vector data processing software, including coordinate handling with possibility of integrating raster information. Should allow development by user.	1	ArcView GIS	The cost for other SW such as MapInfo is about the same.
Ordinary office software (word processing, calculation)	1	MS Word, MS Excel.	

Other Equipment

Table 5. *List of additional equipment*

Equipment	#	Comments
At office		
Light table, format A3	1	Portable "box" that can easily be put directly on a table.
Stereo-viewing instrument	1	
Physical archive for reference data	1	Storage of e.g. printouts of satellite data, interpretations and maps.

Optional Equipment

Apart from the above mentioned equipment, there also exist options of equipment that might not be necessary, at least not in the beginning, but that improve and/or facilitate the work process.

Database for Raster and Vector Data Storage

All digital data such as geographical information, satellite images and important supplementary data should be stored in a database. The database should be organised in a specified and efficient way, and should also be accessible to the IU staff according to well defined security rules. The database needs to be connected to an intranet when the amount of digital geographic data increases to a high number and when several operators are working towards the same data sets. The reason is to make searches for information over a particular area, or searches using other criteria, faster and more efficient. The value of the database, and the efficiency of the IU, will be directly dependent on how well organised the information is stored. This is especially the case when the data volume increases over time, as would be the case for the Safeguards applications.

The database should be an off-the-shelf, well-established market product, preferably constructed to handle both vector and raster data in a comfortable way. There are several database products on the market, but not all of them support raster data handling. Some examples of raster support are:

- Oracle with SDE version 4.0 or higher on top
- INFORMIX Spatial DataBlade

SDE can be seen as an extension to the actual Oracle database. By having SDE on top of the regular database, geographical coordinates can be stored together with the geographical data (raster and/or vector) and it further allows viewing properties such as zooming and rooming of the geographical data. SDE version 4.0 currently only exists in a beta version.

In the case of multiple Imagery Units the different IUs should be able to share the database in order to reduce the costs for purchase and basic system maintenance. The database should then be defined in such a way that the different Imagery Units have restricted access to the data, hence not interfering with the other Imagery Units.

Field Equipment

A differential GPS for clarifying geographical location of the inspector might be of use. This however requires some large equipment to be carried, and it also can take time to register the coordinates, depending upon the number of visible satellites.

Digital map plotter, connected to the GPS, and a field stereo-viewing instrument might be of use for the fieldwork, but are not essential for performing the inspection work.

Light table

A small light table (A3 format) can be used for aerial photos. However, a larger light table might be of use if larger transparencies will be used, for instance showing satellite image data. Aerial photos are often available on transparent film, but in order to produce transparencies from digital satellite data a photo laboratory is required.

Data Storage

Geographical data should be stored on disk with regular back-up routines as well as on physical back-up media such as CD in a media archive. Preferably, a simple searchable media database (e.g. MS Access) should be established, containing information about the data stored on each CD. Examples of such information could be:

- Storage number in media archive
- Satellite info (platform, sensor, scene id, bands, registration date, process level, pixel size etc.)
- Area of coverage
- Producer of data
- Registration date and registration staff member for CD
- Additional comments

Maintenance of Equipment

The equipment should be included in the ordinary technical support, office software and PCs network infrastructure. If particular safety precautions should be considered, due to the type of data handled, a dedicated support staff could be established and an Intranet set up only for the Imagery Units.

Furthermore, support agreements should be signed with the hardware and software purchasers.

Localities

All equipment for each Imagery Unit should be located within the same area, preferably within a lockable room (code lock). If some equipment, i.e. output devices, is to be shared between several Imagery Units these should be stored in a separate area with code lock, well in physical reach for all the Imagery Units. The back-up data from the database, handling the geographical data, should however be stored separately in case of fire or other accidents within the Imagery Unit area.

Future Development

As mentioned earlier, the equipment listed in this chapter has been defined based on the criteria of performing the necessary tasks for the different Safeguard applications with good capacity, but also to be easily expandable for future needs. It has also been designed to allow increased amounts of work and data within a realistic perspective for the future.

The focus for the software has been set towards well-established and functional software that can be easily adapted towards more task-oriented interfaces and procedures.

Data Storage Media

A CD “Jukebox” could be used to automatically load the selected CD, hence allowing the operator to retrieve the needed data without having to load the CD itself. Simply by selecting the desired data set from the media archive (simple database), the “jukebox” will load the CD with the data stored.

Geographical Database and Its Environment

A recommended concept is to store the geographical data, both in raster and vector format, in a database and to create an environment surrounding the database, where the user can search for data via a browser and in the same environment register and obtain metadata. Different maps could then be produced and/or analysis of the data selected by the user could be performed.

Geographical Database - An Example

An example of a system for geographical database handling is the *EnviCat* (Environmental Catalogue), created and supported by Satellus in Sweden. This system is described here and should be seen as an example of a geographical database management system. Follow the link in chapter 7.5 for further reading about the system.

Description

The system is a catalogue for geographical data, with a user interface that can be used via the Internet. The user interface has a browse and search feature that is very similar to Windows Explorer, allowing the user to search data in a structured way. It also consists of a Map Viewer where the user can visualise geographical data and a Shopping bag where the user can collect data for ordering. (Figure 12) shows the basic options of EnviCat.

Platform

The geographical data and the metadata are stored in a relational database, Oracle Version 8, and has been made spatially accessible using SDE (Spatial Database Engine) by ESRI. All this on an NT server. The user interface is developed in Visual Basic and is compiled into ActiveX components. In the first version the user interface can be used from Internet Explorer Version 4 or higher. ArcView Internet Map Server is used for the visualisation of geographical data. Oracle Web Application Server is the intermediary between the Oracle database and the user interface.

Functionality

The flexibility of the system enables the user to operate the program in the following way:

- **For data storage** – to store geographical data the system can act as a Web hotel. The user interface can be customised according to the needs e.g. different restrictions for the users.
- **For visualisation of data** – a user friendly tool for viewing of data. The platform also allows visualisation of image data together with other geographical data.
- **For browse and search** – to browse and search of images, and other, metadata.
- **As a tool for distribution of data** – the distribution facilities enable the user to extract and distribute the data of interest.

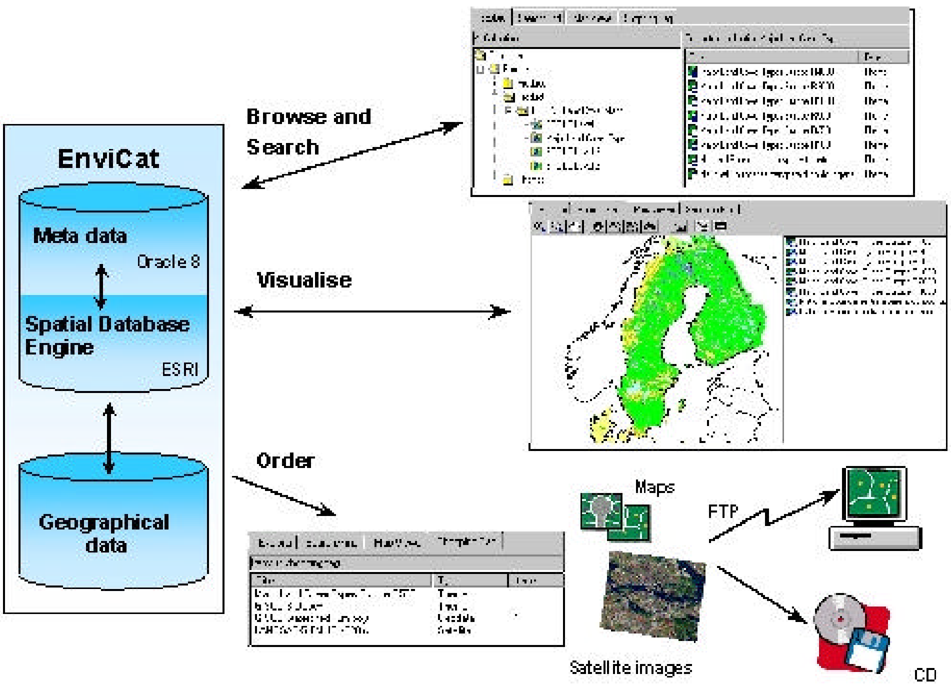

Figure 12. *Overview of the basic opitons of EnviCat.*

Task-Oriented User Interface

To make the work more efficient and user friendly, a user interface could be established, hence minimising the need for the interpreters to obtain a high degree of knowledge of each of the software. Special automatic routines could also be established to perform specific tasks by programming, such as the creation of change images, without needing to run several commands interactively. Some of these routines are easy to create and could be defined by a skilled software user within the IU, while for other adaptations, external support might be necessary from an external consultant experienced in program development and remote sensing techniques and image handling.

Links of Interest

The links were tested and in order on the 24th of March 1999.

Software

ERDAS Imagine

Company site: http://www.erdas.com/

Company UK site: http://www.erdas.co.uk/

ArcView GIS and ArcView Image Analysis

Company site: http://www.esri.com/

Information concerning software: http://www.esri.com/software/arcview/index.html

Photoshop

Company site: http://www.adobe.com/

Information concerning software:
http://www.adobe.com/prodindex/photoshop/main.html or

http://www.adobe.com/prodindex/photoshop/prodinfo.html

LViewPro

Company site: http://www.lview.com/

Information concerning software: http://www.lview.com/about.htm

SDE - Spatial Database Engine

Company site: http://www.esri.com/index.html

Information concerning software: http://www.esri.com/software/sde/description.html

Informix Spatial DataBlade

Company site: http://www.informix.com/informix/

Information concerning software:
http://www.informix.com/informix/products/options/udo/datablade/

Oracle database

Company site: http://www.oracle.com/index_4.html

Information concerning software: http://www.oracle.com/database/prodinfo/index.html

More detailed info (PDF-file):
http://www.oracle.com/database/documents/db_for_the_internet_bwp.pdf

ER Mapper

Company site: http://www.ermapper.com/

Information concerning software:
http://www.ermapper.com/product/ermapper6/prodinfo/index.htm

PCI EASI/PACE and ImageWorks

Company site: http://www.pci.on.ca/

Information concerning EASI/PACE software:
http://www.pci.on.ca/product/epssv61.html

Information concerning ImageWorks software:
http://www.pci.on.ca/product/primage2.html

Other Links

ENVICAT System for handling geographical data

http://www.envicat.com

SILVA GPS and NAVIMAP (digital map plotter)

Company site: http://www.silva.se/

Information concerning GPS: http://www.silva.se/files/gps.html

Information concerning digital map plotter: http://www.silva.se/files/gps2.html

Recommendations

We recommend that standard high-end PCs are used as the basic hardware platform for the Imagery Unit.

The software for GIS/Image Processing should be well established, allow further development, be expandable and handle the common data formats.

Metadata for the imagery and other digital geographical data should be recorded from the start.

A geographical database with data and metadata connected to an Intranet should be implemented when the amount of digital geographical data becomes large. The structure and the rules for distribution of information from the database should be defined during the pilot studies

Project Plan for Implementation

General

This chapter will describe the necessary steps to implement the system and the workflow described in previous chapters. The steps are described as activities and divided into phases and a possible time schedule is shown.

The objectives are to give IAEA a reference project plan for the implementation of commercial imagery, which can be used as a checklist when realising the project. This includes:

- describe the different activities divided into phases,
- describe input and output from the different phases,
- show a possible time schedule and milestones,
- give general recommendations on quality assurance procedures.

Phases

The use of satellite imagery as described in chapter 4 can be done in phases. The division into phases will guarantee a smooth introduction of the new data source and also capture experience, requirements and comments from the staff. It also gives the project manager a tool to monitor the work and reduce the risk of unnecessary costs. It is not necessary to implement all applications at the same time, actually it is better to implement them gradually, but still follow the division into different phases. In chapter 10 "Cost Benefit Analysis" different levels are described (Reduced, Phase 1, Enlarged). By combining these levels and the phases described in this chapter the implementation can be performed smoothly and stepwise.

Initial Phase

Pilot studies

Several studies have been done by different groups indicating the potential use of satellite imagery (see chapter 12, List of Literature). These studies have been performed by personnel outside IAEA. The execution of pilot studies within IAEA will be a "smooth" start where the experience, requirements and comments from the Inspectors can be captured. One of the important objectives of the pilot studies is to validate the use of satellite imagery for the inspectors. The studies have to be performed by the permanent staff supported by personnel with image interpretation skills and include one or more of the applications described in chapter 4. In the pilot studies procurement of hw/sw, training and development of necessary applications can be limited. It is recommended to start with 2 or 3 applications and gradually involve the other applications. Chapter 9 further describes the realisation of pilot studies.

Pre-Operational Phase

Development of a pilot process

The purpose is to implement and test the workflow and manuals prior to the full-scale implementation. This will involve the customisation of software to implement the chosen methods and workflow. It may involve modification to reduce processing time and simplify handling. Selected personnel will be trained.

It is recommended to specify and implement the distribution and storage of data early on. The operational requirements for the different applications can be implemented gradually starting with the "verification" applications.

Pilot operation
The purpose of pilot operations is to test the methodology and workflow prior to the full-scale implementation and operation. The objective is specifically to uncover any problems in the workflow, and to demonstrate readiness for full-scale use.

Development of a full-scale operations process
Any development needed in addition to that mentioned above under "Development of a pilot process" will be performed. Experiences from the pilot operations are evaluated and changes are incorporated. If necessary this will include the re-hosting of software to a full-scale operational environment, the adoption of new operational procedures reflecting the changed environment, the improvement of the operator interface etc. Complementary procurement of hardware and software and training of all the concerned personal.

Operational Phase

This is not a phase but the final goal!

Deliverables

Phase input	**Phase activities**	**Phase output**
	Pilot Studies	
"Implementation blueprint" (this document)	• Production of different products based upon satellite data for selected pilot areas and applications. • Use of satellite products by the selected inspectors. • Comments/evaluation of the satellite products by the inspectors.	• Pilot study products for the selected areas and applications. • Documented comments from the use of satellite products.
	Pre-operational phase: Development of a pilot process	
"Implementation blueprint" (this document) Results from the pilot studies	• Specification of the pilot process • Implementation of the pilot process • Compilation of user manuals. • Procurement of hardware, software and application development • Installation of hw/sw and developed applications. • System qualification. • Training of personal.	• Installed HW/SW • Developed and qualified applications • The workflow (and developed applications) documented in a "User manual" describing each step in the production process • Description of input data required • Trained pilot production personal
	Pre-operational phase: Pilot operations	
Installed HW/SW and developed applications	• Procurement of data • Accomplishment of the work with the help of satellite	• Products for the selected areas and applications. • Generation of supporting material for training in

"Users manuals"	imagery for the selected areas and applications. • Review of the products and the workflow. • Documentation of the recommendations (products and workflow) for a full-scale production process.	the subsequent production phases • Documented recommendations before start of full-scale operations.
Pre-operational phase: Development of a full-scale operational environment		
The pilot system and "user manuals" Recommendations for full-scale operations.	• Introduction of the proposed changes to the workflow and system. • Updating of "users manual" • Verification • Complementary procurement of hardware and software, • Complementary installations, • Training of all personnel concerned.	• A fully documented workflow and "User manual". This should include information on: workflow, general description, input data, commands verifications, processing time, output data, corrective actions.

Milestones

The milestones can be identified as the end of each phase. If there are critical moments within a phase additional milestones can be inserted. At each milestone the status of the project and the deliverables shall be evaluated. Project reviews can be performed. If the result or performed work is not approved corrective actions should be identified.

The following milestones are identified:

- Pilot studies performed.
- Development of pilot process ready.
- End of pilot operations
- End of preparation for full-scale operational environment

At this stage it is not possible to specify the time frame for each phase. The scheduled time is dependent on selected application, number of areas, available staff and other priorities.

Hardware and Software

Procurement

Procurement of hardware and software should follow the standard procedures at IAEA. The following points can be worth evaluatING:

- Does the software require any special hardware configuration, e.g. a large swap area for image processing?
- Are the interfaces between existing and new equipment specified and can the requirements be met? Any comments like "it should work" from the supplier are not good enough.
- A detailed contract where the equipment and services are clearly described is recommended.

Installations

For the installations a document describing the hardware and software configuration should be compiled (part of the contract). This document is a good help for the installations and can be used for verification (chapter System Acceptance Test).

System Acceptance Test

An acceptance test of the hardware, software and installations should be performed. In this "systems acceptance test" all specified functionality is tested referring to the contract, the configuration document and applicable instructions in the quality system.

Maintenance

It is recommended to have maintenance of HW and SW following the suppliers' standard agreements.

Customisation

System

It is to be encouraged that customisation of the system is well specified and documented. This part of the implementation is often handled as a floating process where the programmers are allowed to add some extra functionality based upon what a unique operator wants. If the operator’s requirements are documented and there is a procedure that describes how new functionality is added to the system the system maintenance will be more effective. This is not a lot of extra paper work but a guarantee for an effective implementation, maintenance and a documented workflow that corresponds within IAEA. Figure 13 below shows a tentative workflow including the following elements:

- **Specification**
  Functionality is specified in terms of what the operator requires and also, if the knowledge exists, how existing functionality in the software can be used. These specifications should include customisations of the workflow, routines for data handling (search, archiving, retrieval), routines for storage of the digital interpretation results and requested output (pre-designed layouts),
- **Implementation**
  The specifications are implemented and the documentation of the implementations should include: name of scripts, required software/hardware settings, error handling, installation procedures, etc.
- **User s guide**
  This is a step-by-step guide telling the operator how to use the implemented functionality and possible errors that can occur. This documentation can be done as a hardcopy or integrated as help-functionality in the software. A common outline should be used making it possible to merge all descriptions into a “User’s manual”.
- **Qualification**
  Even if the customisation only includes a few steps it is recommended that a qualification be done. During the qualification an operator supported by the user’s guide, tests the functionality. The qualification should not be done on the same computer as the implementation and not by the person who did the implementation. The qualification is documented in a “qualification protocol” and after completion the customisation is approved for use or not approved (corrective actions have to be specified).

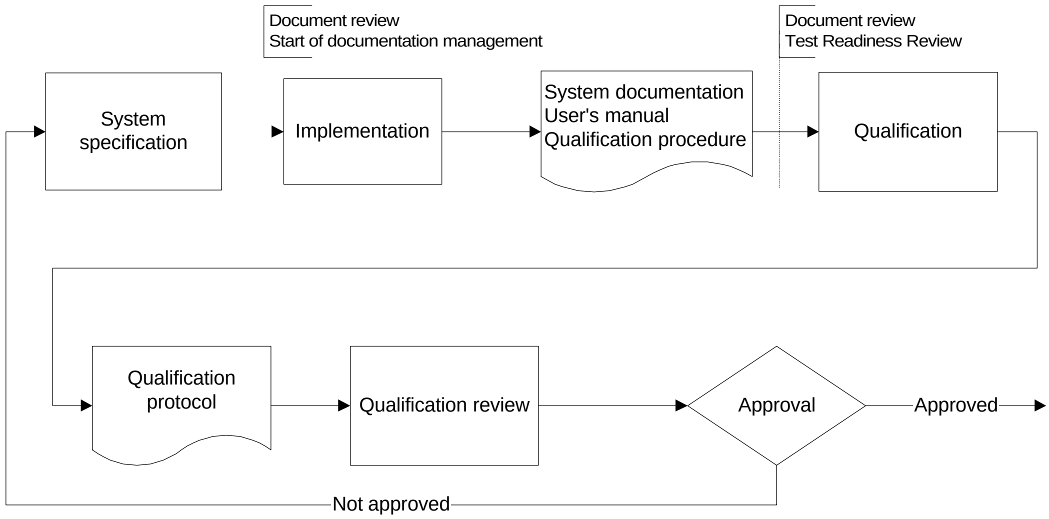

Figure 13. *Model for specification, implementation, documentation and qualification.*

Workflow

The new hw/sw and data have to be described as part of the workflow. For the production work the "User's manual" shall document the different steps that the operator has to go through. Instructions for how to fill out test or review documents will also be included. Figure 14 below proposes a workflow to create and document the defined products in a production phase.

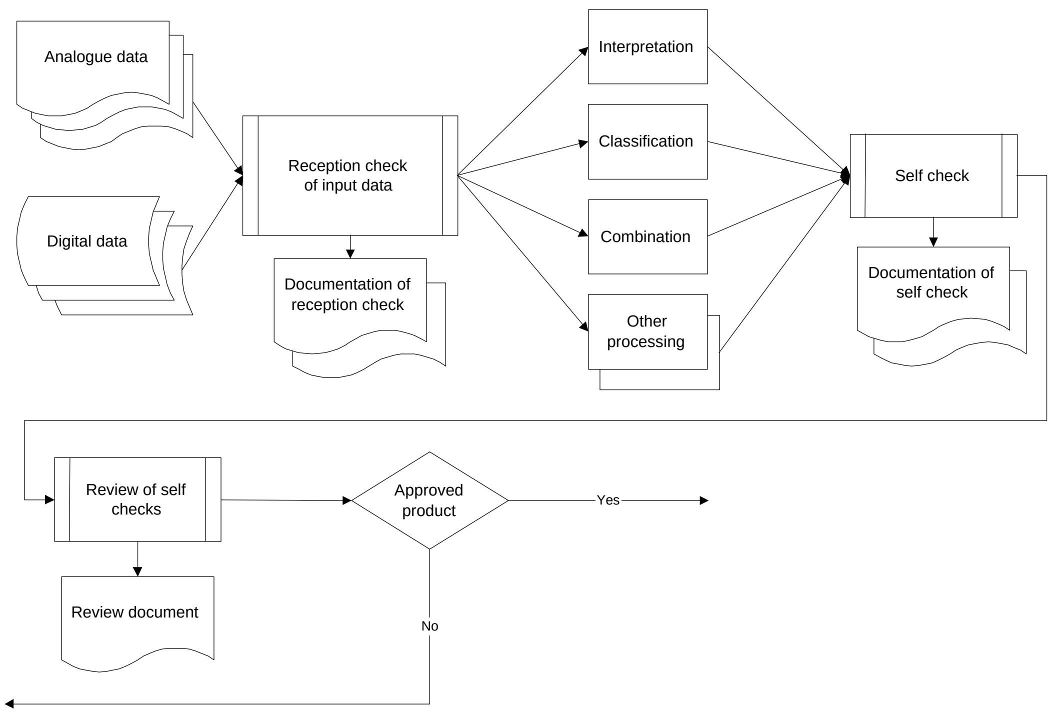

Figure 14. *Model for quality assurance during a production phase.*

Training

The training will involve both “general parts” and more specific parts. The training will be performed as part of the pilot studies, pilot operation or within the operational phase. The training should be performed when the operator will start to use the new data and workflow. It is also recommended that the training be performed in different steps giving the operator the possibility to use and learn some functionality before going to the next step.

Time Schedule

Figure 15 below shows a tentative project plan in the form of a GANT chart with activities divided into the various phases. The different capacity levels as described in chapter 10 can be built up within the pre-operational phase or the operational phase.

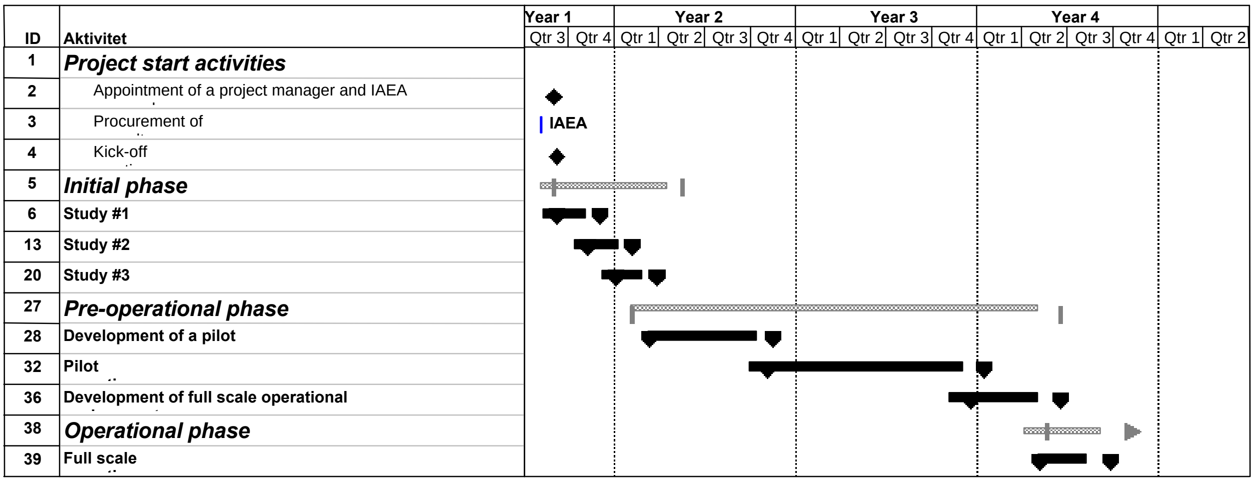

Figure 15. *Tentative time schedule showing the different phases.*

Recommendations

The recommendations are to implement the system and the use of satellite data in a controlled way, by creating clear implementation phases with milestones, and by evaluating each step before going further.

It is further recommended that the different applications are implemented gradually, starting with the applications “Use of imagery as reference information” and “Confirmation of Agency Information”.

The crucial functions to specify in the pre-operational phase are the data storage for the imagery data and the work flow for the different interpretations. These functions are unique for the Department of Safeguards and no standard solution can be accepted from suppliers.

Initial phase - Pilot Studies

General

The objectives of this chapter are to list activities necessary for the realisation of pilot studies. This will include:

- selection of applications,
- selection of areas for pilot studies,
- selection of personnel,
- information to IAEA personal,
- training,
- selection/procurement of hw/sw,
- acquirement of initial data,
- methods for validation,
- recommendations for further implementation.

During the “initial phase” three different pilot studies are suggested.

Assumptions

To make this chapter as concrete as possible the following assumptions have been made:

- The applications used in the pilot studies will be “Use of Imagery as Reference Material”; “Confirmation of Agency-acquired and Agency-generated Information” and “Assessing Open Sources Information” as described in chapter 4.3.
- The areas will be decided in discussions between IAEA and the consultant. Availability of satellite images is important for the pilot studies.
- The work will be carried out in co-operation between the consultant, specialised in image processing, and inspectors at IAEA.
- Necessary HW is described in chapter 7.2.1, during the pilot study the digitising table and large data storage media can be excluded. Existing HW at IAEA will be used if available.
- The advanced image processing work can be carried out using the consultant’s existing SW. For visualisation at IAEA a desktop GIS will be used/procured. A general image processing software such as Photoshop can also be useful.
- Information within IAEA is part of the pilot studies.

Preparation

Initial Data

Suitable satellite imagery has to be procured. Other input data have to be identified and acquired.

HW, SW

Appropriate HW and SW including output device have to be installed at IAEA.

Staff

Inspectors from IAEA have to be appointed and their ordinary work has to be reduced so they can participate in the pilot studies. The number of inspectors taking part in the pilot studies must be large enough to ensure that the skills and experiences gained during the pilot studies can be fully drawn upon in preparation for the start of full-scale operations. In order to reach this goal, at least three inspectors should be selected for training.

Image processing consultants have to be appointed. For the pilot studies, consultants' staff members will fulfil the role of the operators. These staff members will need to undergo brief training as outlined above under the chapter dealing with operators' training. It is envisaged that part of this training will take place at the Agency, while part of the training will be undertaken under the auspices of the Member State Support Programs.

Execution

The activities listed below are executed in an iterative process:

- selection and purchase of satellite images,
- selection and purchase of additional information (maps, etc.),
- image enhancement work,
- the defined satellite/GIS-products for the selected application and area are produced in co-operation between the inspectors and an image interpretation specialist,
- the products are used by the inspectors in their field work,
- feedback from the inspectors on the products,
- new improved products are created in co-operation.

Validation

The experiences and conclusions from the inspectors and the image interpretation specialist are documented, including the following points:

- description of selected area and applications (products),
- estimated time to create the products,

- benefits and disadvantages with the products,
- input data and production time for the products.

This information will be used as input to the cost/benefit-analysis and further definition of the production system.

Information

To gain strong support for the use of satellite data at the Agency we believe internal information is decisive. Therefore different information activities are planned as part of the initial phase. Some suggested activities are described below. The extent and content of the information activities can be discussed and adjusted. It is important that the information part is carried out not only by consultants, but also with a strong participation from the IAEA personnel and managers.

- **Start-up information meeting**
  A half-day meeting where all interested personnel are invited. The meeting will inform about the pilot-studies that are about start. Points on the agenda will be objectives for the pilot studies, involved personnel, selected areas, time schedule, basic information about satellite images and remote sensing etc.
- **Newsletter I**
  A newsletter/short information material that describes the pilot studies (see agenda above).
- **Intranet**
  Information on IAEA Intranet (regularly updated).
- **Results information meeting**
  This meeting will be carried out when the pilot studies are completed. At the meeting the results are shown and discussed. The meeting can be organised as different demonstrations and presentations where the participants, in smaller groups, can take part of the results. Another point on the agenda should be the future activities (pre-operational phase).
- **Newsletter II**
  A newsletter/short information material that describes the results from the pilot studies.

Time Schedule

Figure 16 below shows a tentative time schedule for realisation of the pilot studies.

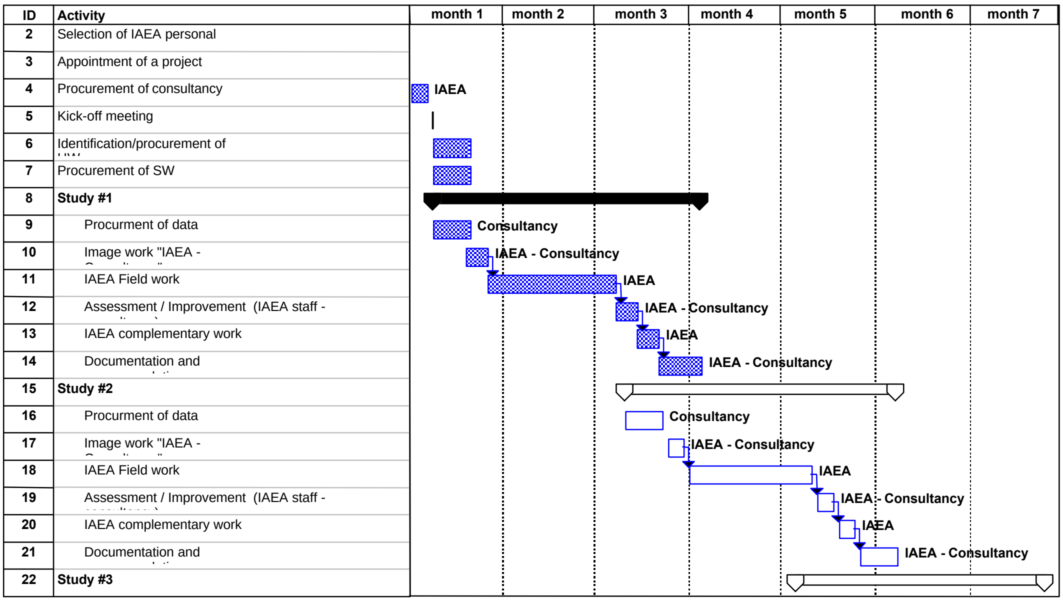

Figure 16. *The figure shows a tentative time schedule for three pilot studies.*

Resources

The following resources are estimated per pilot study:

- Image processing expert, 4 weeks
- Image processing facilities
- Project co-ordinator, general adviser, 2 weeks
- Satellite images (2 SPOT, 1 Landsat, 1 IRS, 1 VHR)
- GIS-licence, e.g. ArcView (vector and raster display functionality)
- Two business trips (Stockholm – Vienna)

The information activities should be discussed and specified before the resources are estimated.

Cost Simulation

Introduction

Purpose and Constraints

The purpose of this chapter is to give the management of the Agency a comprehensive economical decision support for the implementation of satellite imagery at the Department of Safeguards. In this Phase 2 implementation study we have further advanced the cost simulation model as outlined in the Phase 1 study by extending the time scale simulated and by giving several budgetary options. It has been our intention to develop a flexible and modular tool for economical management for building the capacity of the satellite imagery implementation at the Agency.

We have simulated the cost for efficient, decentralised and modular Imagery Units based on the organisational concept as described in chapter 4 *Safeguards Applications Workflow and Procedures*. The simulation estimates the cost for stand-alone Imagery Units. This means that the calculations do not include costs derived from the implementation of satellite imagery but not directly belonging to the Imagery Unit it self. On the contrary, it means that savings by combining resources between the Imagery Unit and other units at the Agency have not been withdrawn. Examples of such costs could be the need for more office space, ‘normal’ office equipment and general technical support. Example of savings could be the joint use of staff knowledgeable in database handling from i.e. the open sources unit, or shared physical disk space.

Input and Context of Cost Variables

Within this study we have used the same simulation model with several input variables as in the Phase 1 study. Figure 17 below outlines the cost calculation model used, and the interrelations between the different variables (spreadsheets) included in the simulation.

The simulation model is based on six different spreadsheets, of which four comprise the quantitative input variables in the model – *Staff*, *Imagery*, *Equipment* and *Training*. The fifth spreadsheet – *Application* - calculates the cost, effect upon the number of inspections, volume of imagery used, and estimated savings depending on which of the safeguard applications is applied. The potential safeguard applications simulated in the model are in accordance with the applications as listed in the document *Safeguards: Sources and Applications of Commercial Satellite Imagery* paragraph IV chapter 2:

- 2.1 Reference information
- 2.2 Confirmation of Agency-acquired and Member State supplied data
- 2.3 Change detection and on-going monitoring
- 2.4 Assessing open source information available to the Agency
- 2.5 Detecting undeclared activities and undeclared sites

The last and "top" spreadsheet – *Budget* - summarises and compares the calculated costs with the present budget situation in the Department of Safeguards.

The arrows are a simplified representation of how costs and savings are transferred between the different variables. An example: the costs for imagery influence the costs for a proposed safeguard application depending on the number of facilities inspected, which also effects costs or savings in the total Safeguard budget.

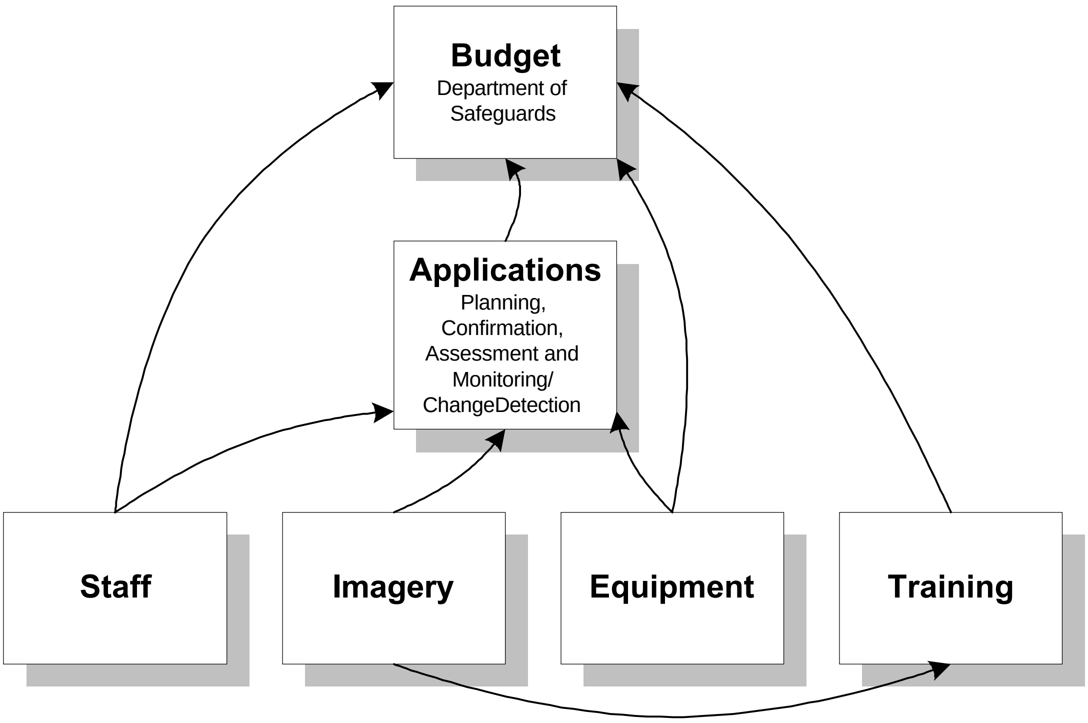

Figure 17. *The interrelation between the six spreadsheets in the cost/benefit model.*

The input variables have been collected from internal Agency documents and other sources, such as The Safeguards Implementation Reports for 1996 and price lists from imagery distributors. In addition to these quantitative variables we have also included the knowledge and experience of SSC Satellitbild in the cost/benefit model. As an example we have reduced the official list prices from the imagery distributors for potential discount for subscription and/or high-volume use. All variables and figures were discussed during reviews at IAEA on 3 December, 1998 and on 2 July, 1999. The input variables used, suggested calculations and the end result from the simulation are further described in more detail below in this chapter.

Cost Overview of Present Activities at the Agency

The Department of Safeguards has developed a model for analysing the cost of inspections at different types of facilities. Expenses are classified in three different categories as *Direct Inspection Costs*, *Inspection Preparation and Analysis Costs*, and *Other Safeguards Costs.* The value of the equipment is depreciated over its expected useful lifetime.

Department of Safeguards Distribution of Costs (1996)		
Type of cost	**Cost USD**	**Distribution**
Direct inspection costs	41 946 000	48%
Inspection preparation	21 737 000	25%
Other safeguards costs	23 339 000	27%
Total	87 022 000	100%

To simplify the comparison between the present (1996) economic situation and the new situation where the Agency introduces commercial imagery as a Safeguard tool, we have in this study used the same breakdown of costs, and equipment depreciation.

Study Approach

Phase 1 Vis-à-Vis the Phase 2 Study

Within the framework of the cost simulation of Phase 2 we have refined the calculation work performed during Phase 1 as described above by:

- fine-tuning of the Phase 1 result due to comments and suggestion from the Agency, independent research groups, and from our own investigations,
- increasing the number of activity scenarios with the addition of a reduced and an enlarged volume of activities,
- evaluating the three activity scenarios by comparing cost, efficiency and capacity,
- calculating the cost of the proposed initial pilot study,
- extending the time scale simulated from one to three years of implementation and calculating the building up of three different levels of imagery capacity during this time.

Thus, compared to the Phase 1 Cost/Benefit study we have created a number of implementation options to choose between for the Agency. These options can be used to accommodate the final capacity and number of Imagery Units due to economical and political constraints. On the other hand we have not in this Phase 2 implementation study elaborated on the potential savings and benefits as a result of the implementation of satellite imagery at the Department of Safeguards.

Simulation Model Used

The refined Phase 2 simulation model is based on calculations as described above in chapter 10.1.2 with four input variables and one application variable. Three suggested ambitions, or scenarios, for the activity volume will result in three different sized Imagery Units with various capacities for handling imagery and Safeguards operations. These three units are in the text below called the *Enlarged*, the *Phase 1*, and the *Reduced* Imagery Unit.

The cost for each one of these Imagery Units is calculated and its efficiency is evaluated. The Imagery Units are further on used as 'building blocks' when simulating the building up of imagery capacity during three years of implementation. Also when calculating these costs we suggest three different ambitions by using Imagery Units with various capacities. These three levels of capacity are in the text below called the *Minimum, Medium*, and *Maximum* level of capacity.

A simplified illustration of the full Phase 1 and Phase 2 simulation model with a proposed capacity target representing the Medium level of capacity is shown in the figure below:

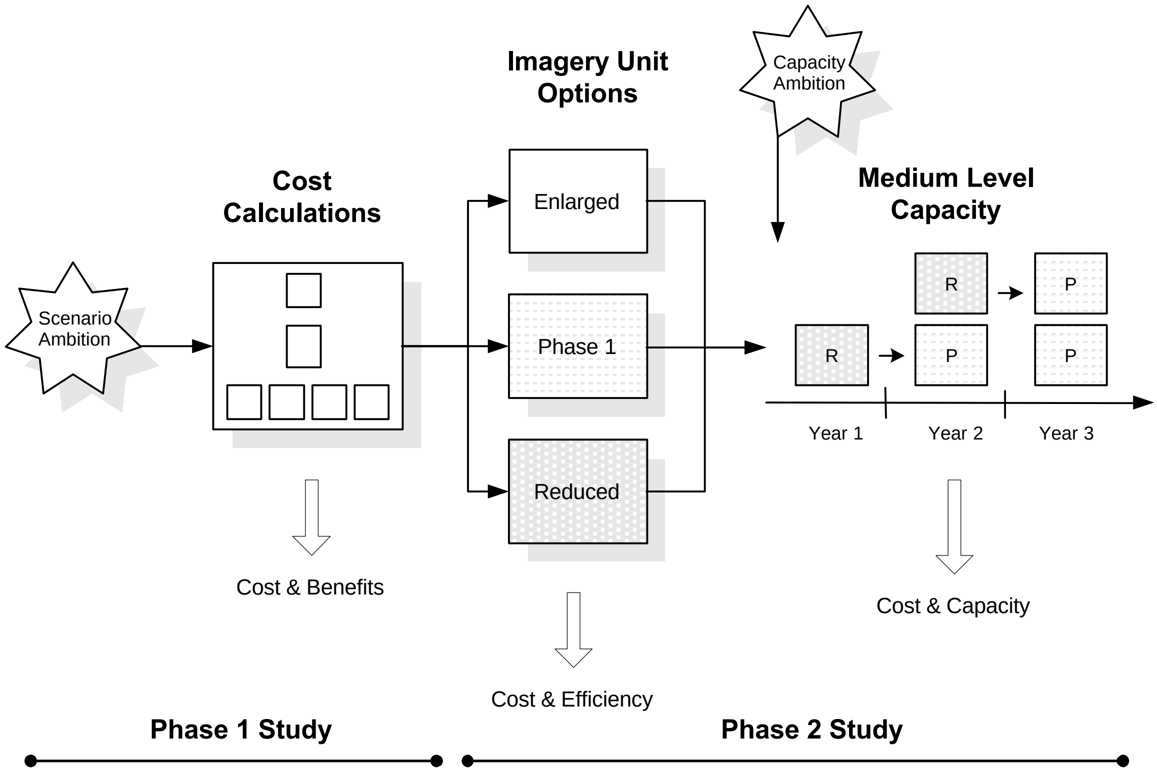

Figure 18*:* *Simplified representation of the cost simulation model. The three years of building up capacity is in this figure represented by the Medium level ambition.*

The cost simulation model used gives the management of the Agency a flexible and modular economic tool in order to create project milestones during the implementation. Thus, the progressive building up of the imagery capacity within the Department of Safeguards can be evaluated and redirected on a yearly basis by using various Imagery Units options as 'building blocks'.

Cost Analysis

Imagery Unit Activities

The general foundation and starting point for the cost calculation is to simulate efficient and decentralised Imagery Units within the IAEA, capable of performing advanced image processing as a tool for various Safeguards tasks. The image processing capacity is suggested to be task- and interpretation-oriented. That is, the daily work should be guided by the Agency's need for imagery-based information and interpretations. Moreover, the activity scenarios are based on the assumption that the Imagery Unit is working extensively with satellite imagery as a complementary source of information as directed by the Additional Protocol.

As discussed in chapter 4 *Workflow and Procedures* the main tasks for an Imagery Unit are the following:

1. Produce and update **digital dossiers** for specific Safeguard issues
2. **Logistic support** by producing planning and reference information for inspections as a complement to available maps, and to support inspectors in the field.
3. Change detection by performing **general monitoring** of ongoing Member State activities and detection of undeclared facilities.
4. **Browse, purchase and organise a database** of satellite data to build up an efficient IAEA imagery library.

Three Potential Activity Scenarios

Based on the four main tasks as described above we suggest three different activity scenarios that fulfil the Department of Safeguards' requirements for a task- and interpretation-oriented support to the ongoing inspection. The proposed activity scenarios are dimensioned to handle all five proposed applications but with different levels of capacity as regards the number of images and feasible support to the inspections. The following three activity scenarios have been chosen:

1. The Phase 1 Activity Scenario - as described in the Phase 1 Cost/Benefit Report
2. The Reduced Activity Scenario
3. The Enlarged Activity Scenario

The Phase 1 Activity Scenario

The number of dossiers under investigation, as simulated in the Phase 1 study, is 90 of which about 50% will be updated each year. The production of reference information and site maps has been calculated to 60 areas each year with a successive building up of a map and site library. Finally, regarding the monitoring investigations of undeclared facilities and activities it has for this scenario been estimated at a volume of 40 areas per year.

As a total for this scenario the *Phase 1 Imagery Unit* will work with approximately 145 activities and purchase about 240 images each year. The distribution of activities and imagery between the different tasks is illustrated in the figure below. A more detailed background and description of this activity scenario is also written in the Phase 1 Cost/Benefit report.

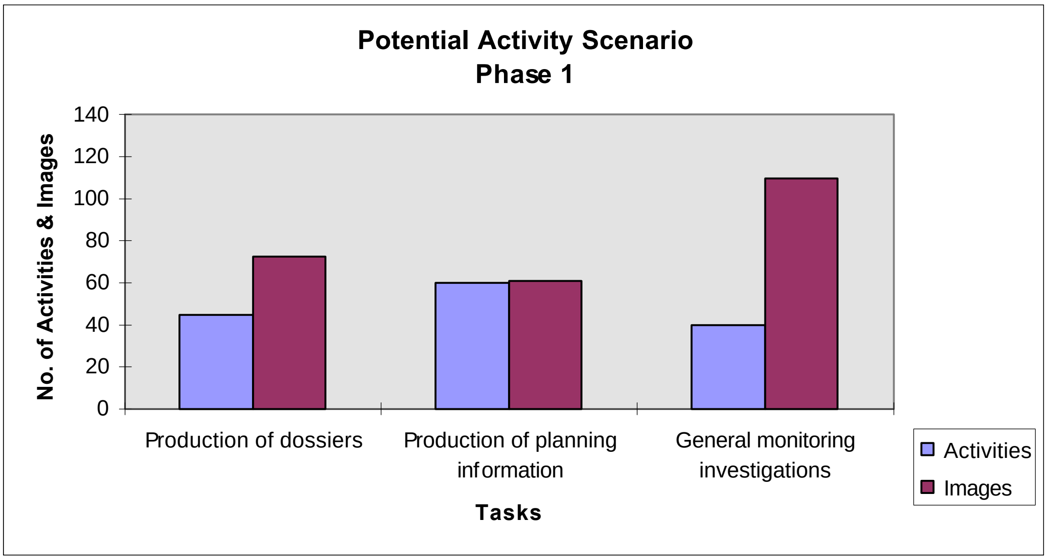

Figure 19*: Estimated number of activities for the Phase 1 scenario measured as production of dossiers, reference information, monitoring investigations and as number of purchased images.*

The Reduced Activity Scenario

As a less costly alternative to the suggested activity volume estimated in the Phase 1 study we have assessed a low-end scenario. Within this Imagery Unit we have drastically reduced the monitoring tasks to a level of 25% of the Phase 1 Imagery Unit capacity. Likewise, we have calculated with a general reduced capacity close to 70% of the Phase 1 scenario.

This means that the dossiers under investigation (app. 90) will be updated each third year. The production of reference information and site maps has been reduced to 40 areas each year with a longer time for creating the map and site library. Regarding the monitoring investigations of undeclared facilities and activities, it can be seen as a test and experiment activity with less than 10 case studies each year.

As a total for this scenario the *Reduced Imagery Unit* will work with approximately 80 activities and purchase about 120 images each year. The distribution of activities and imagery between the different tasks is illustrated in the figure below.

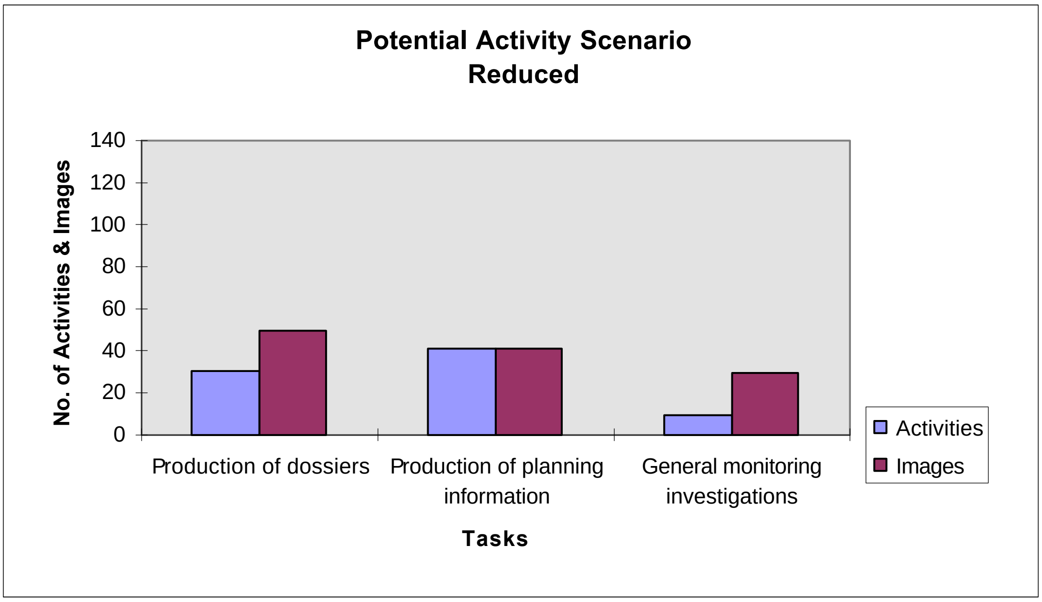

Figure 20. *Estimated number of activities for the Reduced scenario measured as production of dossiers, reference information, monitoring investigations and as number of purchased images.*

The Enlarged Activity Scenario

Finally we suggested an activity volume for an *Enlarged Imagery Unit* that can handle a large number of tasks and is furthermore dimensioned to manage short peak production situations. Within this Imagery Unit we have especially expanded the capacity for production of dossiers and logistics with as much as 35%. The capacity for monitoring is also increased but with 12% compared to the Phase 1 Imagery Unit. This means that the number of dossiers under investigation (app. 90) will be updated almost every year. The production of reference information and site maps has been extended to more than 80 areas each year with a very short build-up time of the map and site library. The monitoring investigations of undeclared facilities and activities can be seen as an on-going and efficient tool for the Safeguards Department Additional Protocol.

In total for this scenario the Enlarged Imagery Unit will work with approximately 190 activities and purchase about 300 images each year. The distribution of activities and imagery between the different tasks is illustrated in the figure below.

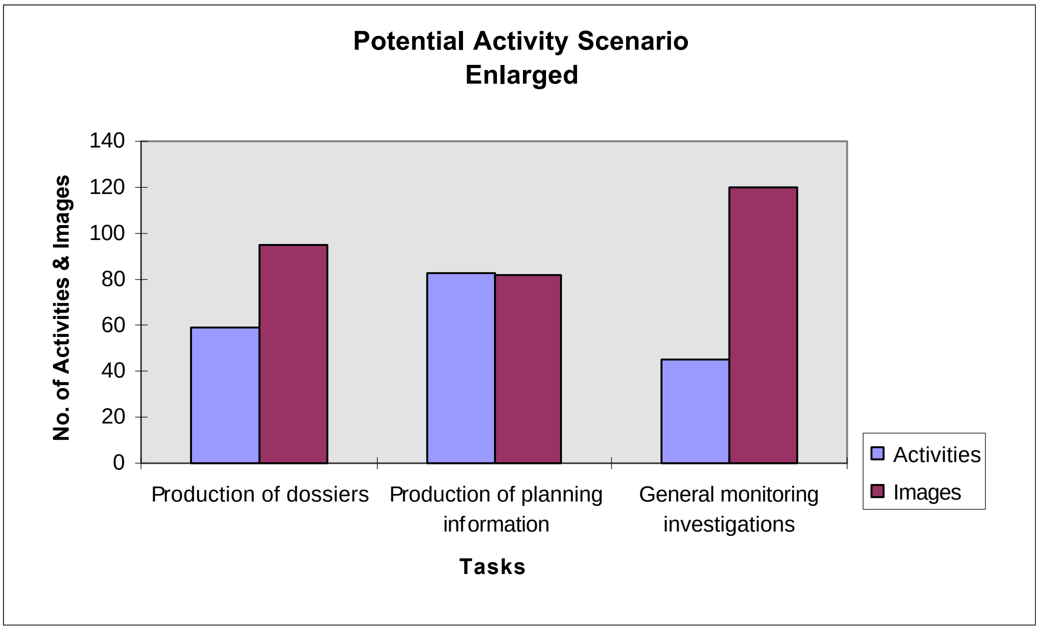

Figure 21. *Estimated number of activities for the Enlarged scenario measured as production of dossiers, reference information, monitoring investigations and as number of purchased images.*

Comparing Imagery Units

Obviously the three Imagery Units require different resources in the form of equipment, staffing, maintenance and imagery depending on the defined activity volume. However at the same time, with the ability to give more extensive support to the Department of Safeguards the potential for saving time and costs is also increased. Thus, the potential savings for each of the Imagery Units differ in the same way as for the cost. The general variation in cost and savings is shown in the figure below.

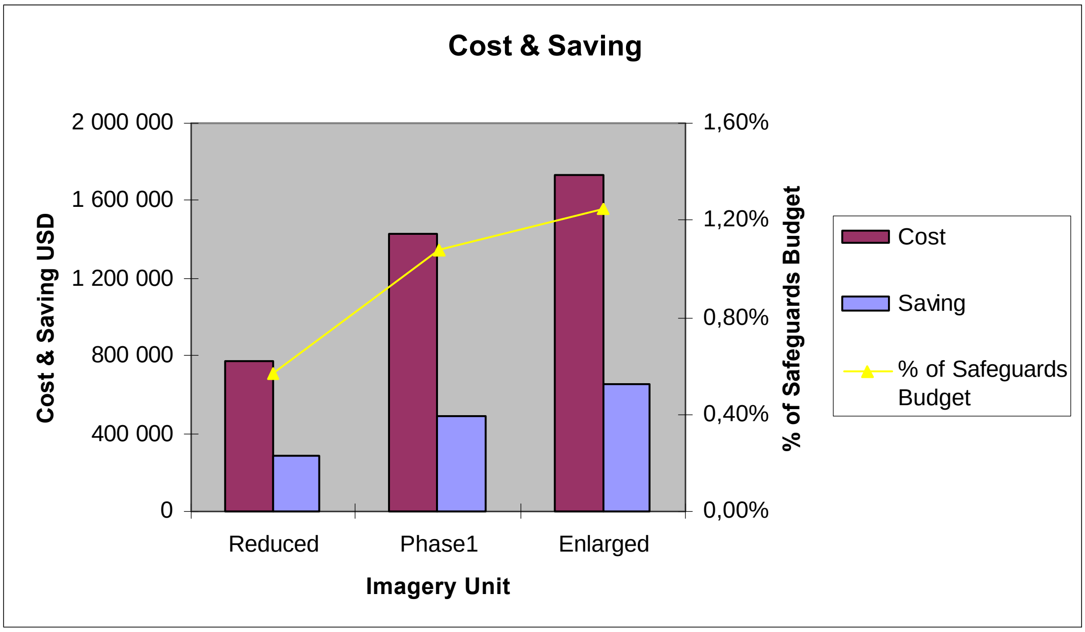

Figure 22. *Cost and potential savings for the various Imagery Units compared to the budget for the Department of Safeguards (1996).*

Compared to the Phase 1 Imagery Unit the costs for the two other units are 54% and 122% respectively. The calculation to obtain the cost and savings figures follow strictly the same concept as was performed during Phase 1, and is further described in the *Phase 1 Final Report* chapter *5.2 Costs of Satellite-Based Methods.* A more detailed comparison of the figures is also given in the chapter 10.3.9 *Cost Overview* below.

Another way of comparing the three Imagery Units is to estimate the ‘efficiency’ in the form of cost per activity. That is, to measure the required IU budget for each individual activity and support to the inspectors. Taking into account the potential savings these values are indicated in the figure below.

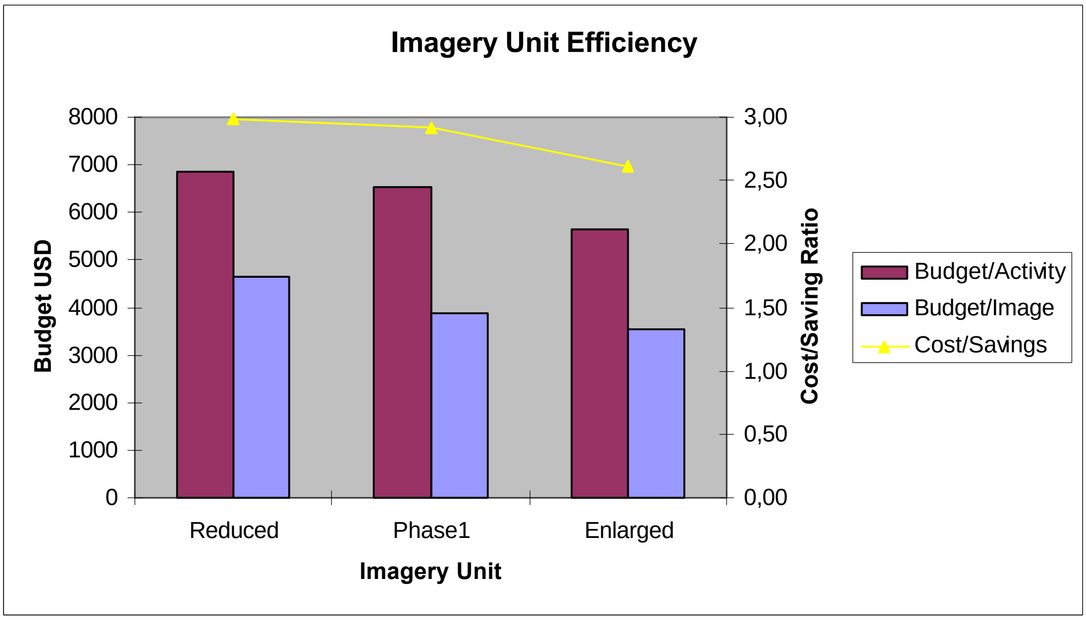

Figure 23. *Estimated efficiency in the form of cost per activity and image.*

As can be seen in the figure the three Imagery Units require almost the same budget per activity. Which means they are dimensioned with the equivalent volume of resources in relation to the tasks to be performed. It can also be seen that the budget in relation to the number of images used is slightly decreasing. Which of course is an effect of unit size and volume 'discount'.

The following chapters explain some of the major effects when changing ambitions from the first suggested Phase 1 scenario to a scenario with a lower or higher activity capacity.

Staff

The volume of activities as outlined above would require several full-time professionals. This is based on an estimated workload for each issue or activity of little less than one man-week. The majority of these new staff members should be of the Professional category (P5/P4), and work with advanced image processing and interpretation together with the inspectors. One staff member should manage the imagery database and is proposed to be of General Service category (G). We also suggest that IAEA apply in addition for national support of 2 cost-free interpretation and processing experts during the early build-up period.

The number of staff needed and the expected normal workload per staff and week for the three Imagery Units is show in the table and figure below:

Imagery Unit	Number of staff	Activity / Staff & Week
Reduced	3	0.68
Phase 1	4	0.91
Enlarged	5	0.93

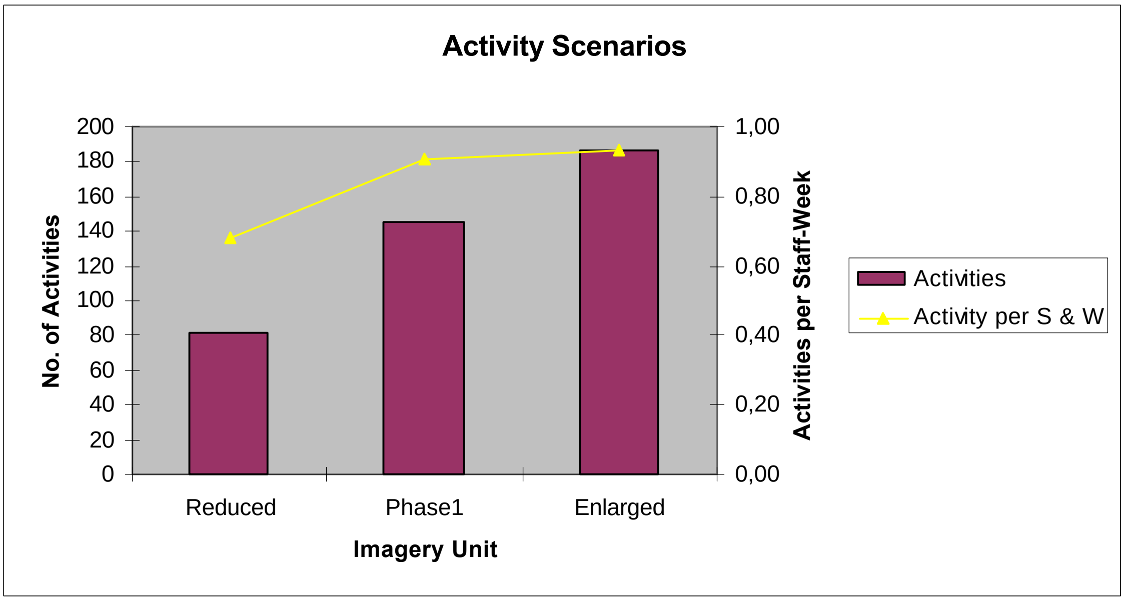

Figure 24. *Activities and workload for the staff in respective Imagery Unit. The workload is measured in activities per staff and week.*

As can be seen in the figure above the staff workload is expected to be less efficient in the Reduced Imagery Unit - 0.7 compared to 0.9 activities per staff-week - since a smaller unit requires non-operational work and management to be distributed among fewer people.

Satellite Imagery

As a consequence of focusing the work of the IAEA Imagery Units towards value-added processing and interpretation activities as described in chapter 4 and 6, there is a requirement on the imagery suppliers to offer more comprehensive pre-processing services. Therefore, we made the following two assumptions when calculating the costs and volumes for images and the pre-processing:

- **Full service data supply system (DSS)**: The imagery suppliers shall take the responsibility, and risk, of giving the Agency the best possible cloud-free coverage of the chosen areas or facilities. That is, browsing, sensor mixture, image selection, geometrical corrections and, if needed, image correlation shall be taken care of by the imagery suppliers.

  This requirement will increase the cost for the imagery by about 30%, but on the other hand remove a large, costly and non-task oriented work from the Agency. Likewise, this prerequisite has also reduced the capacity requirement and costs of the image processing system as specified in this study.

- **A concept of Bundled Images** : In this as well as the Phase 1 study we have calculated the price based on a mixture of different satellites and sensors as this normally is the best way of receiving full area coverage of larger regions. Furthermore, it is also a good interpretation strategy to compare and see differences in sensors and image bands and over time of the same site.

  To fulfil the various needs in the safeguard applications we have introduced two different “image bundles”. A *Standard Bundle* with images available today and with a resolution mainly adapted for reference information and inspection planning. The other *High Resolution Bundle* is suited for confirmation and monitoring applications and requires the new satellite initiatives with resolution better than 5 metres.

Imagery Prices

The Standard Bundle consist of an equal mixture of Spot and IRS data (about 35% each) complemented with Landsat TM and Radarsat imagery. A Standard Bundle price consisting of altogether 100 images will according to the official list price be approximately USD 250 000 for geo-corrected data. Some programming fees are also included.

The High Resolution Bundle also consists of 100 images and includes mainly IRS, KVR-1000, and IKONOS data (5 - 30% each) with a resolution of 6 metres, 2 metres and 1 metre respectively. The total bundle price will be approximately USD 470 000 for geo-corrected information. Some programming fees are also included. The different prices for the two bundles of data depend entirely on the price premium for higher resolution.

On top of these prices we have calculated an additional increase of the cost by 5% to 10% for the browsing and 'bundling' services as described above.

On the other hand, the IAEA as a large and reliable customer could count on a substantial discount. In the simulation we have estimated the discount for the imagery purchase between 10% and 40% depending on the type of data (traditional or high-resolution data) and the type of discount (subscription or large volume). The discount is expected to be slightly higher for the Enhanced Imagery Unit as compared to the Reduced Imagery Unit due to a larger volume of imagery purchase. This means the price for a high resolution '100-image-bundle' with volume discount is calculated to approximately USD 410 000 and USD 460 000 respectively. Of course all these expectations of reduced prices for the Agency are highly dependent on ingenious negotiation with the suppliers of satellite imagery. We cannot emphasise enough the necessity of a resolute purchasing process.

Imagery Unit	Images per year	Images per Activity	Price per Image USD
Reduced	121	1.48	3675
Phase 1	244	1.68	3701
Enlarged	297	1.59	3473

Based on the activity scenarios presented above these prices give the Department of Safeguard an additional cost of approximately USD 445 000, 900 000 and 1 030 000 per year depending on the Imagery Unit scenario used. This is also illustrated in the figure below:

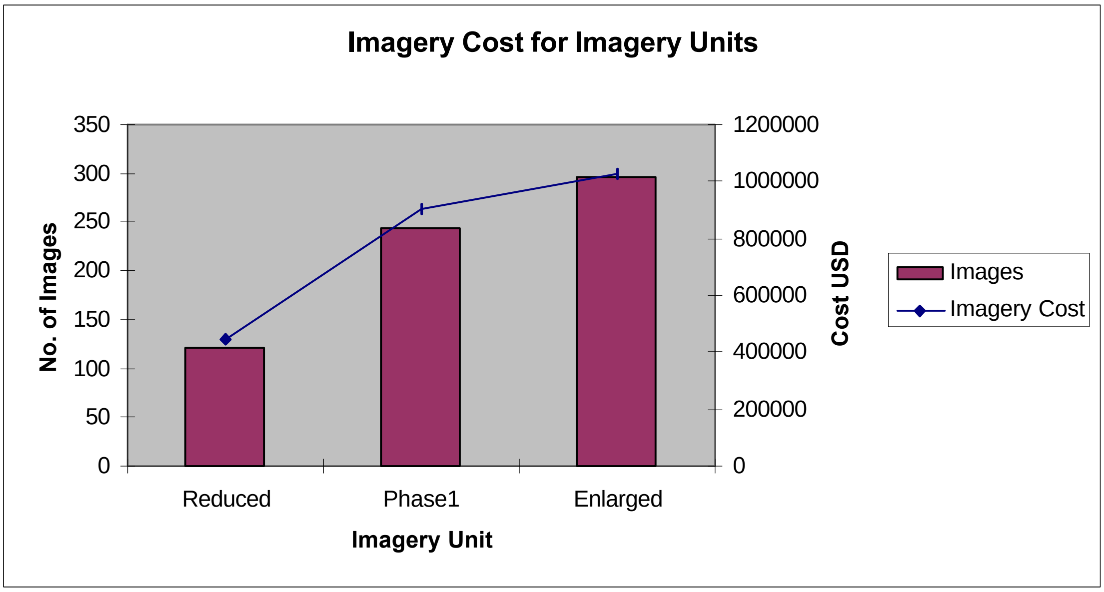

Figure 25. *The number of images and total imagery cost per year for the three Imagery Units.*

The distribution of the imagery costs for various Safeguard applications as defined in chapter 4.3 are shown in the figure below. This figure illustrates the situation for the suggested Phase 1 Imagery Unit scenario. That is, a large part of the images will be used within the extended applications for accessing open source information and for monitoring purposes. Please observe the differences in price between these applications and the reference information applications.

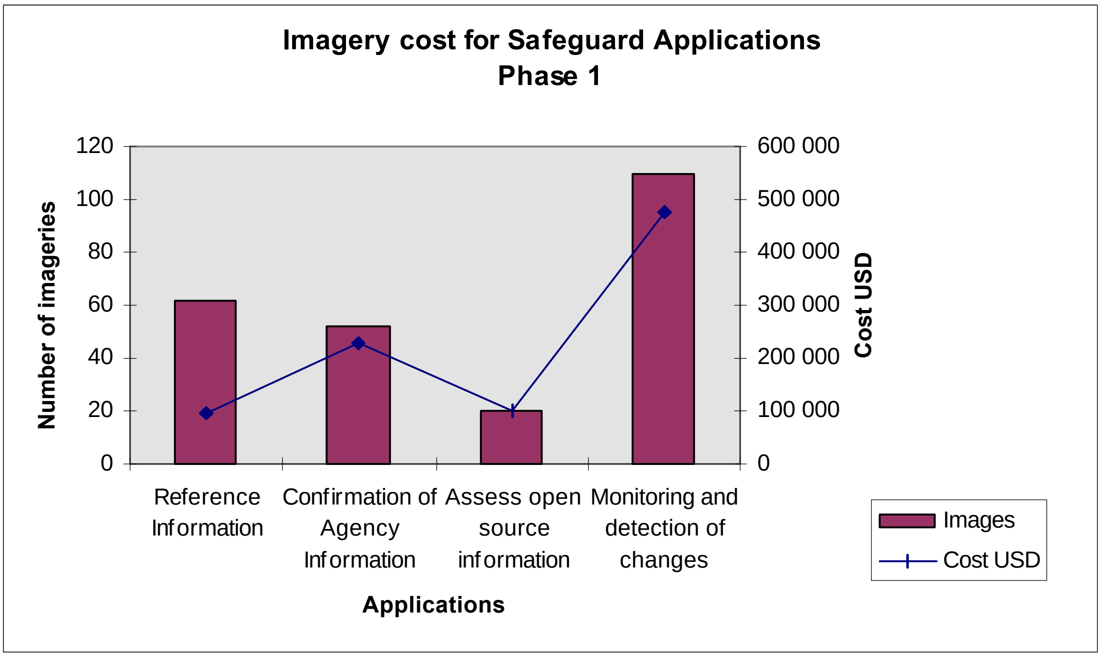

Figure 26. *Distribution of imagery costs for each safeguard application.*

In this Phase 2 study we have also included the effect of falling prices during a three year period due to increased competition among the satellite data providers. It is foreseen that the prices for imagery will be reduced by a factor of 5 to 10 % especially during the next year when additional commercial suppliers enter the market. Another driving force for a reduced imagery cost will be the new price strategy for Landsat 7, where prices for data already have been reduced significantly.

Equipment and Maintenance

A refined estimation of the cost for equipment has been performed within the Phase 2 study. The calculation is founded on the previously discussed concept of small, stand-alone Imagery Units capable of executing all image and GIS processing as specified in chapter 4. The equipment is furthermore adjusted to manage the number of activities and volumes of imagery as is required for the various Imagery Units. Of course the equipment is also tailored for the team of staff depending on the Imagery Unit used – i.e. 3, 4 and 5 personnel. The cost calculation is based on the software and hardware specification as discussed previously in chapter 7.

Compared to the calculations made in the Phase 1 study we have in this study also included the cost for a minor in-field processing capacity by adding portable PCs to the Imagery Unit staff. In addition we have also increased the ability to store images and other data by enlarging the size of the storage media.

Software and Hardware

The equipment is based on the use of several advanced remote sensing software systems, and some standard Geographical Information Systems (GIS). As supporting software we also suggest that some basic and general-purpose image processing systems should be included. The central idea is to create a dynamic image processing environment with a large amount of functionality by adding software from different suppliers. The suggested number of in-office systems for the various Imagery Unit is as shown in the table below.

Imagery Unit	RS Software	GIS Software	Image Processing
Reduced	3	1	2
Phase 1	3	2	2
Enlarged	4	2	3

The basic hardware in turn is adjusted to the software and especially to the volume of data. Thus, the hardware cost for the three Imagery Units is estimated from different numbers of high capacity PCs connected to a fast Intranet (switched Ethernet > 100 Mbit). The choice of input and output equipment, on the contrary, does not deviate substantially between the Imagery Units.

Equipment Cost

The total cost for software is estimated at USD 36 000 to 61 000. Altogether the cost for hardware is estimated at USD 61 000 to 120 000. Including support and maintenance by software suppliers the total acquisition for the equipment will be approximately USD 100 000 to 180 000. In the cost simulation this investment is depreciated over three years will be approximately USD 33 000, 50 000 and 61 000 for the three Imagery Units. That is, almost twice as large a cost for the Enhanced Imagery Unit compared to the Reduced one. However, if we take into account the capacity difference between the three Imagery Units we find that the cost per activity will actually be reduced with increased Imagery Unit size. These figures can be compared in the figure below.

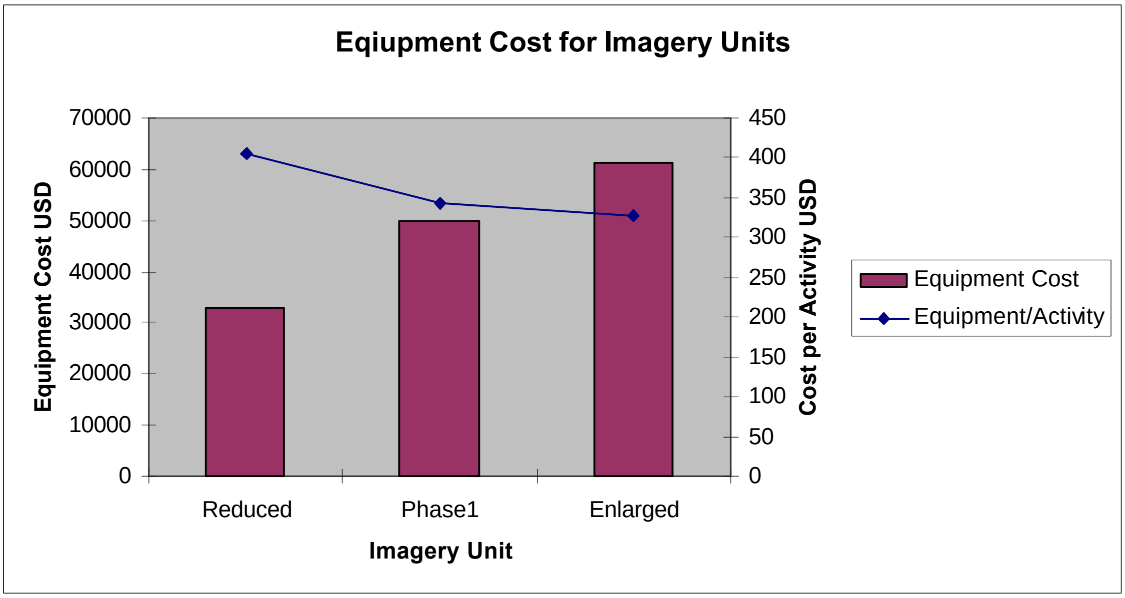

Figure 27. *The depreciated cost (three years) for equipment and maintenance. For comparison the equipment cost per activity is also calculated.*

The diagram below shows the distribution of various equipment costs for the Phase 1 Imagery Unit (excluding the imagery storage). The distribution in percent does not differ significantly between the three Imagery Units.

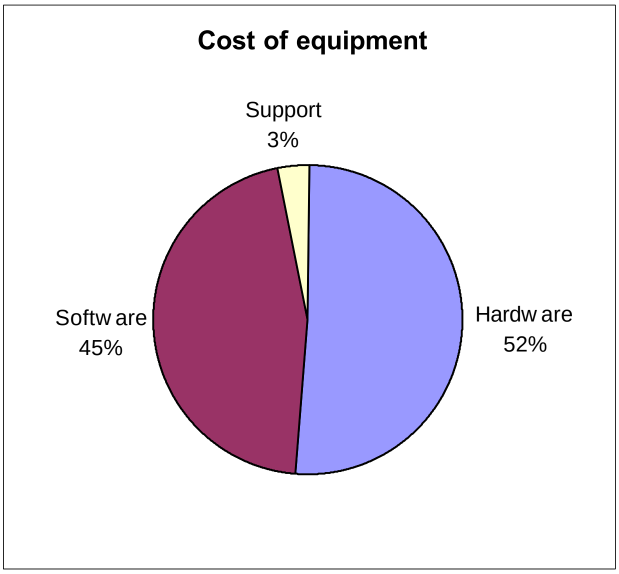

Figure 28. *Distribution of costs for equipment.*

Training

The training included in the cost analysis comprises only external courses that are not expected to be supported charge-free by the Member States support programmes. Likewise training anticipated to be best performed internally by staff of the Agency - such as giving nuclear cycle background to the processing operators – is not included either. An example of the type of courses included in the simulation is specialised training in the use of software and hardware equipment for the inspectors. That is, most of the competence development program as suggested in chapter 5 is expected to be supported by Member State programmes and a specially set up training programme.

The following table shows the number of student-days and the cost involved:

Imagery Unit	Student-Days	Cost (USD)
Reduced	115	54 000
Phase 1	125	56 000
Enlarged	140	60 000

Cost Overview

When summarising the simulation of the total cost for implementing commercial satellite imagery at the Department for Safeguards the result will vary between **USD 840 000** and **1 700 000 per year** depending on the scenario ambition the Agency chooses. These figures are presented in more detail in the following table using the same breakdown of costs as used by the Agency.

Type of cost (USD)	Reduced Scenario	Phase 1 Scenario	Enhanced Scenario
Direct inspection costs			
Salaries	0	0	0
Travels	0	0	0
Analysis of samples	0	0	0
Other	0	0	0
Inspection preparation			
Management	0	0	0
Negotiations	0	0	0
Non-inspection travels	0	0	0
Processing and analysis	310,000	430,000	550,000
Other (=images)	444,000	902,000	1,030,000
Other safeguards costs			
Computers and maintenance	33,000	50,000	61,000
Development and training	54,000	55,000	59,000
Other	0	0	0
Total	841,000	1,437,000	1,700,000

The total cost figures above represent 1.0, 1.6 and 1.9% of the present (1996) Department of Safeguards budget.

Cost of the Initial Phase   Three Pilot Studies

The following section provides an estimation of the expenses needed for the first pilot studies within the Initial Phase of the implementation. The cost calculation is based on the assumption that inspectors and other IAEA staff participate in the pilot study partly at the image laboratory of a consultant. And vice versa, the image processing consultant, acting as an IU operator, will partly perform the study at the Agency in Vienna.

As outlined in chapter 9 it is suggested that three different types of studies should be performed over a period of more than 6 months.

Type of costs	Cost (USD)
Staff of consultants	70,600
Imagery Laboratory	13,000
Satellite Imagery	69,000

GIS Software	3,500
Consultants travel & accom.	10,600
Total	166,700

Cost for Different Levels of Imagery Capacity

As suggested in chapter 3 *Actions and Opportunities of the Imagery Unit* a decentralised approach to the satellite data implementation could mean a dedicated IU for each operational division at the Department of Safeguards. Thus, for more than one operational division to have this capability more Imagery Units would be created, one for each of the operational divisions concerned.

By utilising the capacity of the various Imagery Units as 'building blocks' when increasing the overall capacity and expanding the potential for satellite imagery to several operational divisions it is possible to have a gradual expansion. As described in chapter 8 *Project Plan for Implementation* we suggest a three-year implementation divided into several phases. A successive building up and implementation of the IAEA satellite imagery potential is wise for several reasons, but especially since the implementation project as such will be more manageable, easy to modify and in the end less costly.

Three Cost Scenarios

The possibilities for combining the three Imagery Units as described earlier in this chapter are nearly unlimited. Within this Phase 2 study we have as an example simulated the cost for three different scenarios all representing a gradual increase of the imagery capacity over three years and with a schedule that is possible to review and modify. These three scenarios give the Agency a vast span of imaginable implementation possibilities.

The three scenarios - called Minimum, Medium and Maximum scenario – have the following features in common:

- Several Imagery Units are used to build a stronger and more potent capacity.
- The IUs are used to constitute a gradual building up of the imagery capacity.
- The implementation period of three years is divided into phases feasible to review.

The cost model used for the scenarios is simply the same as described earlier for each IU. That is, each IU adds its cost to the total investment. Of course one could argue that there is a potential opportunity for savings when several Imagery Units are merged. This however requires further calculations.

The Minimum scenario starts with one Reduced IU and after three years ends with one Phase 1 IU. The Medium scenario also starts with one Reduced IU, however after three years this scenario will have two Phase 1 IUs. Finally, the last example of how to gradually increase the imagery capacity is shown in the Maximum scenario starting with one Phase 1 IU and ending with three Enlarged IU. These examples are also presented in the figure 29 below.

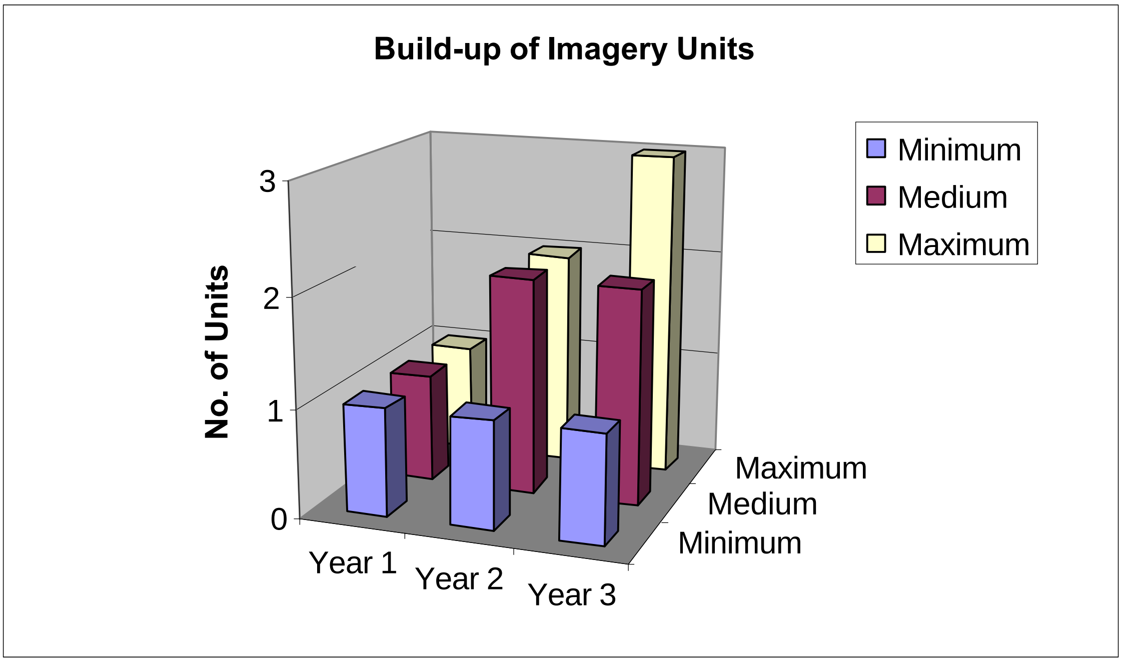

Figure 29. *Gradual building up of several Imagery Units over three years.*

Of course this more or less strong increase of the imagery capacity will also be reflected in the cost. Using the calculation performed earlier and aggregating these figures accordingly, the development of cost during the three years will be as shown in figure 30 below.

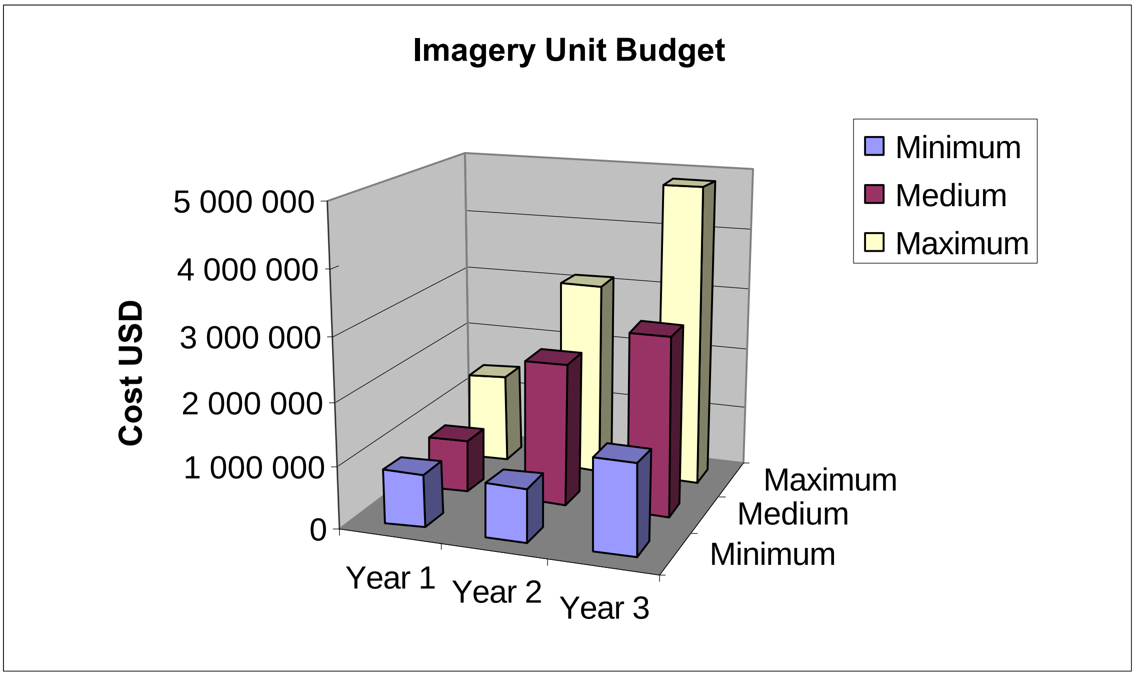

Figure 30. *Example of necessary investment costs for a gradual increase of several Imagery Units.*

Recommendations

It is of the utmost importance that the Agency clearly defines and quantifies the capacity, ambition and activity volume of the Imagery Unit. This should be done early in the implementation and integrate experiences from the pilot studies.

Generally speaking, we feel that the Enlarged Imagery Unit is better implemented as a single centralised entity. Based on the efficiency calculation and the relative costs for staff, imagery and equipment, all figures point towards the Enlarged IU as the best choice. On the other hand, the difference between the Phase 1 and the Enlarged IU is not particularly large, and this should be compared to the USD 300 000 difference each year in total cost.

In any case, the Agency is recommended to apply all the three described IUs of various sizes as 'building blocks'. This will give experience in calculating an implementation of a decentralised approach with dedicated IUs for each operational entity.

We would also like to remark that implementing an Imagery Unit staffed with less than three professionals would not be in accordance with the ambition to create an operational support organisation within the Agency. Such a small unit could, however, act as a test or 'seed unit' for possible future enlargement. An economically acceptable alternative in such a case could be to outsource the entire Imagery Unit to an existing remote sensing organisation.

Finally it should be noted that the major limiting factor as regards the production throughput of 'dossiers' and other activities is the number of staff. This means the IU personnel should be selected with particular care to obtain a productive and efficient team.

Conclusion

Main Findings

The following points are the main items arising during the study of the Implementation Blueprint. The findings are an aggregated summary from this Phase 2 study as well as the main points from the Phase 1 Cost/Benefit analysis.

A realistic and effective concept

The studies confirm that the proposed concept of relatively small and efficient Imagery Units using high-resolution data within the Agency will be a sound and feasible undertaking. Such a unit capable of performing advanced image processing as a tool for various safeguard tasks will give the Agency a new and effective instrument for reference, monitoring, verification, and detection of declared and undeclared activities.

Specify objectives and role

One important prerequisite for the success of the implementation and the operation of the Imagery Unit is that the Agency clearly and in measurable terms defines documents and distributes the objectives and role of the Imagery Unit internally to all concerned, and to the Member States.

Consistent activity scenario and processing capacity

One of the most important results from the cost/benefit simulation is the fact that the Agency’s wish for a reduced number of inspections, by imagery support, will mainly be limited by the number of staff at the Imagery Unit. It is important that the volume of imagery, number of tasks and the number of staff are consistent when implementing the imagery systems. Furthermore, these capacity parameters must be coherent with the objectives given for the Imagery Unit.

Phased and evaluated implementation

We recommend a phased implementation of satellite imagery. Each phase should be evaluated and measured by several means and methods. Volume and time for the processing flow, input/output-ratio in the form of cost and benefit and general experiences from concrete case studies are three suggested evaluation methods.

Work Organisation and Processing Flow

We believe it will be as important to have a thorough planning of the management and organisation of the Imagery Unit as it is to draft the type of equipment to be purchased during the implementation. Therefore, we would like to emphasise the following recommendations:

Four main work areas

The Imagery Unit should be organised so it clearly reflects its intended objectives and role. We recommend the IU to be organised within four main work areas: production of ‘dossiers’; reference information; monitoring and verification; and organisation of an imagery database. Each work area could be dedicated to one staff member running one of the four main tasks.

Tuned processing flow

One key parameter in the creation of an Imagery Unit will be the ability to integrate the software, hardware and associated equipment into a single, well-tuned processing unit. It is recommended that the Agency carefully specify and evaluate the integration and 'hand-shaking' between the various off-the-shelf sub-systems.

Training plan for staff

The skills and competence of the staff within the IU will be a key issue for the Agency. It is therefore recommended that a long-term recruitment and training plan is formulated early in the implementation.

Data Supply System

The introduction of a so-called full service Data Supply System (DSS), where the image supplier(s) take the responsibility and risks in creating and delivering the best cloud-free coverage of a chosen facility, should be the basis for an effective imagery purchasing approach at the IU. Successful negotiations regarding price and service with the suppliers will substantially influence the overall cost.

Imagery production system

We recommend that standard high-end PCs be used as the basic hardware platform for the Imagery Unit. The software for GIS/Image Processing should be well established, allow further development, be expandable and handle the same data formats. The structure and the rules for distribution of information from the database should be defined at an early stage of the implementation.

Implementation and Pilot Project

A three-step implementation

The recommendations are to implement the system and the use of satellite data in a controlled way, by creating clear implementation phases with milestones, and by evaluating each step before going further:

- Initial phase – 6-12 months
- Pre-operational phase – 1-2 years
- Operational phase – after 3 years.

Fine tuning and customisation

The significant customisation of the IU system that is envisaged must be well specified and documented. This part of the implementation should be handled as a floating process where programmers are allowed to add extra functionality based upon the operators', needs and requirements.

Gradual implementation

It is further recommended that the different applications are implemented gradually, starting with the applications “Use of imagery as reference information” and “Confirmation of Agency information”.

Unique solutions for Safeguards applications

The data storage for the imagery data and the work flow for the different applications are the two crucial functions to be specified in the pre-operational phase. These functions are unique for the Department of Safeguards and no standard solution can be accepted from suppliers.

Cost Analysis

Objective versus cost

The Agency should as early as possible define and quantify the capacity ambitions and required activity volumes for the Imagery Unit. These ambitions determine the size and cost of the Imagery Unit. This study gives the tools and some examples for this decision.

To summarise costs

When summarising the simulation of the total cost for implementing commercial satellite imagery at the Department for Safeguards, the result will vary depending on the ambition level of the scenario the Agency chooses.

Imagery Unit	Reduced	Phase 1	Enlarged
Total cost (USD/year)	841,000	1,437,000	1,700,000
Relative cost (%)	1,0	1,6	1,9

The relative cost figures above represent the percentages of the present (1996) Department of Safeguards budget.

Lower limit

Implementing an Imagery Unit staffed with less than three professionals will not be in accordance with an objective to create an operational support organisation within the Agency. An economically acceptable alternative in such a case could be to outsource the entire Imagery Unit to an existing remote sensing organisation.

List of literature

IAEA Safeguards. 1998. Sources and Applications of Commercial Satellite Imagery. Report, Version November 18, 1998. IAEA, Vienna.

IAEA Safeguards. 1998. Legal Issues Associated with IAEA Use of Commercially Available Satellite Imagery. Draft Paper presented at the IAEA Technical Workshop on Sources and Applications of Commercial Satellite Imagery, 16 and 17 September 1998. IAEA, Vienna.

ImStrat Corporation (Principal Investigator Pacquette, J.P.). 1998. Potential Applications of Commercial Satellite Imagery in International Safeguards. Report No. AECB 97-221 (prepared for the Canadian Atomic Energy Control Board). ImStrat Corporation, Ottawa.

Jasani, B., Richter, B., Stein, G., Ward, M.D., and Killinger, M. 1996. Enhancing IAEA Safeguards Using Commercial Satellite Imagery: A Pilot Study. UK and the Federal Republic of Germany Safeguards R & D Programme. SRDP-R240, JOPAG/12.95-PRG-265, Task A.16/JNT D882. Department of War Studies, King’s College, University of London.

Jasani, B., and Stein, G. 1995(?). Space-based Monitoring of Proliferation of Weapons of Mass Destruction. Final Draft. Proposal for a study for the Joint Research Centre, European Commission. Department of War Studies, King’s College, University of London.

Jasani, B., Niemeyer, I., and Morton, C. 1998(?). The use of multi-temporal satellite-based images for nuclear safeguards and other applications. In? pp. 297 – 311.

Martucci, L.M. 1998. A Concept and Preliminary Methodology for Assessing the Use of Imaging Satellite Sources. Presentation material presented at the IAEA Technical Workshop on Safeguards: Sources and Applications of Commercial Satellite Imagery 16-17 September 1998.

Pacquette, J.P. v. ImStrat Corporation.

Rost, T., and Rosengren, M. 1998. Mycket högupplösande satelliter. (In Swedish, “Very High Resolution Satellites”), Report to the Swedish Space Board, X-PUBL-39, Swedish Space Corporation, Solna, Sweden.

Truong, Q.S., Keeffe, R., Baines, P., Pacquette, J.P. S.D. Potential Applications of Commercial Satellite Imagery in International Safeguards. Paper. Canadian Safeguards Support Program, Atomic Energy Control Board, Ottawa.