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Classification of uranium reserves/resources

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FOREWORD

Current projections indicate that nuclear energy generation will grow at a rate between 0.6% and 1.9% to the year 2015. The fuels needed to feed these reactors will still primarily come from mine production. Contributions from reprocessed fuels and low enriched uranium (LEU) blended from highly enriched uranium (HEU) from demilitarized weapon material and government stockpiles are expected to increase, but not to exceed 20% of the annual projected requirements. Plutonium from weapons and military stockpiles are not anticipated to be equivalent to more than a few percent of requirements over a period of 20 years or more.

Projections of future availability of uranium to meet present and future nuclear power requirements depend on the reliability of uranium resource estimates. Lack of harmony of the definition of the different classes of uranium reserves and resources between countries makes the compilation and analysis of such information difficult. The problem was accentuated in the early 1990s with the entry of uranium producing countries from the former Soviet Union, eastern Europe and China into the world uranium supply market. The need for an internationally acceptable reserve/resource classification system and terminology using market based criteria is therefore obvious.

This report presents the results of three IAEA consultancy meetings on uranium classification systems held over the period 1992 to 1996. The consultancies were organized to explore the different classification systems and to provide a forum for bringing uranium resource reporting into harmony.

The first meeting held in Vienna on 22–25 June 1992 brought together specialists to define the different uranium resource classification systems, establish their similarities and differences and then explore how these systems could, if necessary, be changed to make them more consistent. Based on the results of this meeting it became clear that the methods of estimating and identifying the amount of resources were similar. However, the systems developed under the command economies of the former Soviet Union and the Council for Mutual Economic Assistance (CMEA/COMECON) do not classify the resources by their relative level of economic attractiveness (or production cost) in the same way as do market economic based systems. Furthermore the resources are reported as in situ, with no allowance for mining and milling losses.

The objective of subsequent consultancies was to define what changes are necessary to bring the various systems into harmony and provide for uniform and meaningful classification of all uranium resources. The meetings were intended to assist specialists and policy makers of participating countries in transforming their systems to be consistent with international standards. The meetings also provided a forum for monitoring progress with harmonization.

During the meetings it was agreed that the classification system developed jointly by the IAEA and the Nuclear Energy Agency of the OECD, as published in the world report "Uranium Resources, Production and Demand" (the Red Book), should be the international standard for reporting uranium resources.

This publication was compiled from participants' contributions and findings of the Consultants Meeting on Harmonization of Uranium Resource Assessment Concepts held in Vienna from 22 to 25 June 1992, and two Consultants Meetings on the Development of a More Meaningful Classification of Uranium Resources held in Kiev, Ukraine on 24–26 April 1995 and 20–23 August 1996. The large number of consultants, many of them cost-free to the IAEA, that participated in all three meetings suggests that the theme of the meetings was of particular importance to resource specialists in these countries.

The IAEA wishes to thank the consultants for their contribution. In addition, it expresses appreciation to the management of the State Geological Enterprise "Kirovgeology" (A. Bakarjiev, General Director) of Ukraine for providing the venue and support in the organization of the two meetings in Kiev. Special thanks are extended to V. Ruzicka of the Geological Survey of Canada who acted as chairman, and assisted with co-ordination and interpretation in all three meetings. The IAEA officers responsible for the organization and implementation of the meetings were E. Müller-Kahle (first meeting) and D.H. Underhill, of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

CONTENTS

SUMMARY

Since the mid-1960s the IAEA has strived to develop a comprehensive inventory of recoverable uranium resources to fuel the world nuclear electric programme. To achieve this objective it has carried out many activities, including co-operating with the Nuclear Energy Agency (NEA) of the OECD in the Joint NEA-IAEA Uranium Group. An important result of this co-operation was the development of a classification system used in preparing the inventory of uranium resources published in the world report on uranium: "Uranium Resources, Production and Demand", otherwise known as the Red Book. The classification system is given in Appendix I.

This system is based on two considerations: the confidence level of the estimates and the market based cost of producing (or recovering) the resource. In this system all of the *Known*, or identified resources, are classified in the *Reasonably Assured Resources (RAR)* and *Estimated Assured Resources — Category I (EAR-I)* categories. The RAR consist of the most well known resources while the EAR-I include the rest of the known resources. The other categories: *Estimated Additional Resources — Category II (EAR-II)* and *Speculative Resources (SR)* include resources known with less certainty. This uranium resource classification system is the standard for making official country resource submissions for the Red Book. All countries are encouraged to openly report their uranium resources using a classification that is fully compatible with the system.

The collaboration with the NEA includes an ongoing effort to improve the consistency of national reporting of uranium resource inventories. This helps assure the Red Book information is useful for projecting future uranium supplies. Underlying this effort is the continuing concern that inconsistent national reporting of uranium resources could make the Red Book information less useful (and less reliable) for projecting future uranium supplies.

Prior to 1990, public information on uranium resources was only available for the World Outside Centrally Planned Economics Area (WOCA). Similar information for the non-WOCA was not published. However, with the political changes in the early 1990s it became apparent that the uranium producing countries of the former non-WOCA were becoming suppliers to the world uranium market. The new supply source includes the uranium producers of the former Soviet Union (FSU), (Kazakhstan, Russian Federation, Ukraine and Uzbekistan) as well as the COMECON countries (Bulgaria, Czech Republic, Hungary, Mongolia and Romania). The latter group had previously sold much of its uranium production to the FSU.

Several of these countries have large uranium resources, as well as the potential of continuing to produce uranium for the world market. With the development of a more open system following the dissolution of the Soviet Union and its trading alliance in 1991, some of these countries reported large amounts of uranium resources for the 1992 Red Book. At that time concerns developed regarding increasing uncertainty in estimates of the world uranium resources. Prior to the dissolution of the FSU and the COMECON block, all of the member countries used resource classification systems that were similar to the system used by the FSU. It also became apparent that these systems differed from the system used in preparing the Red Book.

For this reason, the management of Geologorazvedka Corporation, the uranium exploration branch of the Ministry of Atomic Energy (Minatom) of the Russian Federation, recommended that the IAEA organize a meeting to harmonize the terms and definitions used in uranium reserve and resource classification. The first consultants meeting, held in June 1992, focused on defining and understanding the differences between the system developed and used for preparing the Red Book and those of the former Soviet Union, and eastern European countries. Subsequent meetings further analysed similarities and fundamental differences between the various methodologies used in estimating each country's uranium resources.

This publication provides a summary of the results of the consultancies on the topics. It also includes the more important national reports presented on the topic. First, it introduces the

development and evolution of the classification system used by the NEA-IAEA Uranium Group (paper by R.M. Williams), followed by comments or comparisons made with this system (by Russian Federation and Ukraine). These papers are followed by descriptions of different methodologies used in estimating the national uranium resources in Canada, Czech Republic, Kazakhstan, Russian Federation, Ukraine, United States of America and Uzbekistan. As can be appreciated, the problem of uniform approach in classifying mineral commodities reserves/resources has been the concern of countries with long mining traditions. A list of published papers on this subject is given in "Reference Material".

It was clear from the first consultants meeting that each country develops and uses a uranium reserves/resources classification system considered appropriate to meet its own specific political and economic situation. Most of these systems are based on two basic parameters, degrees of geological confidence and an economic measure related to the cost of production. These are often known as two dimensional classifications.

The primary focus of the meetings was to seek a way to harmonize the uranium resource classification systems used in the former Soviet Union (as well as in eastern Europe) with the one used in the Red Book. Achieving this result would assist emerging countries in evaluating their uranium resources using economic market principles. It would also improve the reliability of the world uranium resource inventory. The shortcomings commonly observed in the way many countries report their resources was also discussed. It can be generally stated that this series of meetings made progress in helping to understand the similarities and, more importantly, the fundamental differences between these systems. The difference between the two systems stems from two distinct philosophies, free market and centrally planned command economies, under which the two primary resource classification systems were developed. It implies two very different processes from which the systems evolved and were implemented.

FIRST CONSULTANCY, VIENNA, 22–25 JUNE 1992

The initial consultants meeting provided the first opportunity to discuss and compare differing methods of classifying resources used by countries active in uranium deposit development and production. Participation in this meeting was from the Russian Federation, Czech Republic, Hungary and Romania as well as Canada, Germany, France and the USA. It was learned that the various systems have several features in common. All of them differentiate the resources into two main groups: known and undiscovered. In addition, most countries further subdivide undiscovered resources into that portion which is expected to occur in areas with well defined geology containing known deposits, and those less well known areas containing speculative resources. This last category is highly uncertain in nature.

It was learned that there are similarities in the methodology used for estimating the amount of contained uranium. Furthermore there was a reasonable agreement between the various classes of confidence levels used in the FSU system (and the COMECON) and the Red Book. For example, most of these countries used a resource classification system with classes designated A, B, C_1 and C_2 to describe resources ranging, respectively, from those with a high assurance of existence, to those with a low assurance of existence. It was learned that the A, B and C_1 classes are similar to RAR, while C_2 is similar to EAR-I. There were, however, substantial differences in reporting this information. For example, while RAR and EAR-I in the Red Book include only recoverable resources, the FSU traditionally included in situ resources, with no allowance for losses in mining and milling, and with no depletion for production.

The greatest differences existed regarding the classification of resources by production cost. The Red Book refers to "the market based cost of production of the resource", while the other systems are based on centrally planned economics. S.S. Naumov and M.V. Shumilin (this publication) reported that prior to 1991 an economically based system, ranging from low to high cost was used in the

<table>
<tr><th></th><th colspan="3">← Known Resources →</th><th colspan="3">← Undiscovered Resources →</th></tr>
<tr><td>NEA/IAEA</td><td colspan="2">Reasonably assured</td><td>Estimated additional I</td><td>Estimated additional II</td><td colspan="2">Speculative</td></tr>
<tr><td>Australia</td><td colspan="2">Reasonably assured</td><td>Estimated additional I</td><td colspan="3">Undiscovered</td></tr>
<tr><td>Energy, Mines and Resources Canada</td><td>Measured</td><td>Indicated</td><td>Inferred</td><td>Prognosticated</td><td colspan="2">Speculative</td></tr>
<tr><td>France</td><td>Reserves I</td><td>Reserves II</td><td>Perspective I</td><td>Perspective II</td><td colspan="2"></td></tr>
<tr><td>Fed. Rep. of Germany</td><td>Proven</td><td>Probable</td><td>Possible</td><td>Prognosticated</td><td colspan="2">Speculative</td></tr>
<tr><td>South Africa</td><td colspan="2">Reasonably assured</td><td>Estimated additional I</td><td>Estimated additional II</td><td colspan="2">Speculative</td></tr>
<tr><td>United States DOE</td><td colspan="2">Reasonably assured</td><td colspan="2">Estimated additional</td><td colspan="2">Speculative</td></tr>
<tr><td>CIS</td><td>A + B</td><td>C 1</td><td>C 2</td><td>P 1</td><td>P 2</td><td>P 3</td></tr>
<tr><td>CSFR, Hungary, Romania</td><td colspan="2">RAR</td><td>EAR - I</td><td>EAR - II</td><td colspan="2">S R</td></tr>
</table>

The terms illustrated are not strictly comparable as the criteria used in the various systems are not identical. "Grey zones" in correlation are therefore unavoidable, particular as the resources become less assured. Nonetheless, the chart presents a reasonable approximation of the comparability of terms

FIG. 1. Suggested approximate correlations of terms used in major resource classification systems

Russian Federation, Kazakhstan, Uzbekistan and Ukraine. They indicated, however, that "Any coincidence between the (described) cost limits in dollars as used in IAEA accounting system, is purely accidental."

The classification systems used by the FSU and COMECON were established to meet objectives of the centrally planned socialist economic system. An important objective of the system was achieving full resource recovery of the strategic commodity uranium. The goal was recovering as much of the resource as is reasonably practicable, with little or no consideration given for cost of production. Resources left in the ground and not extracted were considered to be wasted.

A formal uranium resource classification system was defined by Soviet law. It was implemented and monitored by the State Committee of Natural Resources, or its equivalent. The law defined the methodology to be used in making resource estimates, including defining the minimum cutoff grades for use in estimating resources in different types of uranium deposits. The cutoff grades were uniformly low, supporting full resource recovery. A minimum grade of 0.03% U was to be used for deposits to be produced by conventional mining. A minimum of 0.01% U was used for deposits to be mined using in situ leach technology. Once estimates were prepared using the prescribed methodology, designated representatives of the responsible Committee reviewed the estimates and reported to the Committee whether they should be included in the official inventory of "on balance" (i.e. economic) resources. Changes to "on balance" estimates could only be made with the approval of the Committee.

The participants also agreed that the following terminology and definitions used in resource classification have the same meaning among the various systems:

- *in situ resources*: a quantity estimated on the basis of geological data and a geological cut-off grade only (methods of calculation of cut-off grade are summarized in IAEA Technical Reports Series No. 255 — Methods for the Estimation of Uranium Ore Reserves, 1985);
- *producible resources:* in situ resources, which can be produced using existing mining and milling techniques; the quantities are estimated applying a factor equivalent to mining and milling losses; it was recognized, however, that in the case of in situ leaching, the producible resources can be higher than the in situ resources;
- *recoverable resources:* producible resources which can be recovered under given economic criteria and conditions.

At the meeting it was considered that the cost categories used in the Red Book at the time (1992): < US $80/kg, $80–$130/kg U, and > $130/kg U did not present sufficient detail in view of the market price over the last decade, and therefore needed refinement and adjustment. It was also noted that the classification used in the former Soviet Union employed cost categories that have little or no relevance to those used in countries with a market economy.

Probably the most important outcome of the first meeting was reaching agreement on the modification of the approximate correlation of terms in the mineral resource classification system used in the Red Book. This new chart, Figure 1, was incorporated in the subsequent issues (1993 and following) of the Red Book. The meeting also helped develop a common understanding of uranium resource classification methods and systems.

SECOND CONSULTANCY, KIEV, 24–26 APRIL 1995

Following completion of the first consultancy it became apparent that harmonization of uranium resource classifications would take some years to develop. The IAEA's consideration of the uniform classification of uranium resources was therefore reactivated nearly 3 years following the first consultants meeting. The April 1995 meeting provided an opportunity to revisit the problem of harmonization of uranium resource classification after a number of countries had sufficient time to analyse their position with reference to the classification used in the Red Book. Some of these considerations are reflected in the critical comments made by the participants from Kazakhstan, the Russian Federation and Ukraine as presented in this publication. This was also the first meeting including representatives from Kazakhstan and Ukraine.

The consultants discussed the large increases in uranium resources that had recently been reported in the Red Book. It has, however, become apparent that many of these resources may have little relevance as uranium supplies for reactor fuel over the next 10 to 15 years, or possibly ever. The principal reason is that, compared to IAEA estimation practice, several of the estimates have fundamental flaws.

The resource classification system used in the Red Book is generally recognized as providing a meaningful estimate when the appropriate methodology is followed in preparing the estimate. This involves preparation of the mineral inventory, followed by completion of an economic analysis of the cost of production. Only those resources meeting the RAR and EAR-1 criteria should then be included in these classes. Substantial errors were identified with the reported RAR and EAR-1 from some countries.

Some of the problems are:

- based only on resource inventory of in situ or geological class resources
- no consideration for recoverability
- no adjustment of estimate for past production
- no meaningful economic analysis of production cost
- failure to take into account all costs in economic analysis; such as infrastructure or rehabilitation following operation
- obsolete economic evaluation, conducted up to ten years or more before present, which do not take into account changes in economic conditions, as well as changing technology and the present day requirements for safety, health and environmental protection.

While progress was made in securing a unanimous recommendation regarding resource classification, it was apparent from the discussions and the written presentations that there are substantial reservations regarding universal adoption of the NEA-IAEA system. It is concluded that substantial discussions and training will be required before the many differences between free market and central planned economic areas are sufficiently resolved to find a high level of harmonization of resource estimates.

It was also apparent that changes could only occur as the respective governments recognize and accept the use of market economic principals. Furthermore, acceptance by the participants in these IAEA meetings of the concepts of production cost classification is only the first step in developing and adopting a new system. It is then necessary for these specialists to introduce the concepts, together with proposals for a revised system, to the government specialists such as members of the State Committee responsible for classifying resources. The representatives of the respective State Committees must then convince law makers to introduce new laws, and/or eliminate old laws, prescribing how uranium resources are to be classified. It is noted that V.I. Lovinyukov of the State Committee of Geology, Ukraine, took part in the last 2 meetings on which this report is based (April 1995 and August 1996). This direct participation by a representative of a responsible State Committee is expected to help facilitate adoption of an improved resource classification system.

The experts' *recommendations* from this meeting are:

(1) For the category Reasonably Assured Resources (RAR), it is suggested that the current Red Book definition be maintained.

(2) The quantity of resources should be reported as the amount remaining in the deposits. (Resources that have been produced should be deducted.)

(3) The classification box as used by the Member States of the Commonwealth of Independent States (CIS), from the 1993 Red Book (Figure 1), will be maintained. It will now represent Kazakhstan, Russian Federation and Uzbekistan. A new classification box will be added showing the system as used in Ukraine.

(4) All RAR will be submitted to the Red Book as "recoverable". However, if any country chooses to submit information as in situ, or geological, it will be necessary to report these resources in a separate table.

(5) If resources are reported that do not meet all of the technical and economic requirements of RAR, the resources should be classified in a category of lower confidence.

(6) Suggestion to redefine Undiscovered Resources in the Red Book. These should be named "Prognosticated;" without any subdivision. They are to be reported as in situ.

(7) It is useful and necessary to indicate in the Red Book submission the mining technology to be used in producing the uranium (i.e. open pit, underground or in situ leaching) This recommendation is based on the survey of NEA Uranium Group Members.

(8) As requested in the 1995 Red Book Questionnaire, it is confirmed that it is very useful to report what segment of the resources are contributory to an Existing or Committed production centre.

(9) Resources associated with by-product production should be reported.

(10) Cost categories of \$40, \$80 and \$130/kg U should be maintained and reported. No other cost categories should be reported in the Red Book.

To provide a better understanding of terms related to uranium resources used in Russia and Ukraine a list of useful terms is included in Appendix III.

THIRD CONSULTANCY, KIEV, 20-23 AUGUST 1996

In addition to the group that participated in the first and/or the second meetings, the third meeting was attended by a representative from Uzbekistan, an important uranium producing country.

It was observed at this meeting that substantial progress has been made and continues to be made in developing and accepting uranium classification systems that are consistent with the NEA-IAEA system as used in the Red Book. The Red Book uranium resource classification has been reviewed and is also judged to be consistent with the recently developed United Nations International Framework Classification for Reserves/Resources — Solid Fuels and Mineral Commodities.

The systems of evaluating the quantity and concentration of uranium is relatively uniform throughout the world and appear, in the cases reviewed, to be generally consistent with international standards. The systems of economic evaluation used to estimate production costs were in the past, much less consistent. In some cases, such as in the former Soviet Union and COMECON countries, there was no comparable system for production cost evaluation, as it is known in the market economy system. Over the last few years, however, systems taking into account production costs are being developed and introduced in these developing market economies which classify uranium resources. Substantial progress is being made in revising old and/or developing new resource classification systems. As indicated below, countries that participated in these 3 meetings on Harmonization of Uranium Resource Classification Systems are in various stages of re-evaluating resources using the new economically based systems.

The stage of development of these classification systems are:

- Czech Republic: complete;
- Kazakhstan revised classification under consideration;
- Russian Federation: classification system under development;

– Ukraine classification system under final review;
– Uzbekistan classification system under development.

Recommendations and statements made by the country representatives

Russian Federation: S.S. Naumov; M.V. Shumilin

The following is proposed:

- To retain without changes the existing classification of resources as used in the Red Book (RAR, EAR-I, EAR-II, and SR) and cost categories (< US $40/kg U, $40–80/kg U, and $80–130/kg U).
- To determine the exact requirements for each category of explored resources and the requirements for assigning the range in their economical evaluation in distributing Red Book Questionnaires.
- Ask all respondents to update their information taking into account specified requirements.
- To develop separate evaluations of resources for underground mining and ISL method in the next publication of the Red Book.

Ukraine: A.C. Bakarjiev

The following information should be included in the next Red Book: The information for both in situ and recoverable uranium resources.

Kazakhstan: V.P. Zhelnov

(a) Recommendation for the Red Book classification

- To report information about uranium resources in 2 parts: for those to be mined using conventional mining and those to be mined using in situ leach technology.
- To take into consideration that uranium resources in Kazakhstan classified as P1 also meet the requirements of EAR-1.

(b) At present the uranium resources in Kazakhstan are estimated and classified using the classification system of the former Soviet Union. Kazakhstan is developing a new classification of mineral resources. The classification of uranium resources will be developed taking into consideration recommendations of the IAEA. The classification will be developed by the State Committee of Mineral Resources, with input from KATEP, and the State Geological Organization "Volkovgeology".

Czech Republic: J. Šuráň

Recommendation:

- The existing resource categories as used in the Red Book are suitable, and should be maintained. The presently used cost categories should also be maintained.
- All RAR should be submitted to the Red Book as recoverable resources. If any country chooses to submit information as in situ resources, it will be necessary to report the resources in a separate table.
- Resources should be segregated into 2 groups:

    - resources suitable for conventional mining
    - resources for mining using in situ leach technology.

Statement:

The uranium industry of the Czech Republic finds the NEA-IAEA uranium resource classification system to be fully acceptable. There are no plans to create a new national classification of uranium resources.

Uzbekistan: N.S. Bobonarov

- The representative of Uzbekistan supports the recommendations made by S.S. Naumov and M.V. Shumilin of the Russian Federation.
- A new classification of mineral resources is being prepared in Uzbekistan. It is planned to be consistent with the UN International Framework Classification. It is not yet complete.
- The uranium resources of Uzbekistan are also being re-evaluated with full consideration given for market economy considerations of cost of production. This new estimate may be complete by early 1997.

Canada: V. Ruzicka

Canada fully supports the Red Book system of uranium resource classification. It continues to re-evaluate its national uranium resource base on a regular schedule. With the closure of the last operating mine in the Elliot Lake area in June 1996, the remaining Elliot lake resources have been classified as un-economic.

CONCLUSIONS

It may be concluded that these meetings provided a forum for leading specialists from the respective countries to exchange information and discuss the strengths and weaknesses of the various systems. They provided a central focus where the specialists could develop mutually acceptable concepts for uranium resource classification.

While the meetings did not achieve all of the objectives, it appears they may have been instrumental in helping to clarify some of the uncertainties associated with the uranium resource estimation. Furthermore the meetings may have also helped contribute to the development of more uniform uranium resource reporting by several countries. An indication of this progress is given in the Findings of the Third Consultancy held in Kiev, August 1996. At that time it was reported that a revised market oriented uranium resource classification system had been completely adopted in Czech Republic; was under development or consideration in Kazakhstan, Russian Federation and Uzbekistan; and was under final review in Ukraine. While it is probable that a completely uniform resource inventory will only be developed once market economy principles have fully evolved, progress toward this objective is taking place.

The meetings discussed in this report took into consideration related activities on the subject of resource classification organized by the Geneva based Economic Commission for Europe (ECE) of the United Nations. This group developed the "United Nations International Framework Classification for Reserves/Resources — Solid Fuels and Mineral Commodities", the United Nations first attempt to develop a uniform resource classification system in 1979. However, it was unable to reach a reasonable conclusion at that time. In 1992, responding to a proposal from the German Government, the ECE resumed work on a 3-dimensional classification based on a system developed in 1991 by the Federal Institute for Geosciences and Natural Resources of Germany. A summary of this classification, which was developed as an international system for assessing all solid fuel and mineral deposits under market economy systems, is given in Appendix II. It was found that the classification system used in the Red Book is generally consistent with the UN International Framework Classification System.

Related work in the IAEA includes the attention paid to the methodology for uranium resource estimation, as indicated by meetings and publications related to the subject. For example, methodology for resource estimation is described in IAEA publications: Methods for the Estimation of Uranium Ore Reserves: An Instruction Manual, Technical Reports Series No. 255, IAEA, Vienna (1985), and Methods for the Estimation and Economic Evaluation of Undiscovered Uranium Endowment and Resources: An Instruction Manual, Technical Reports Series No. 344, IAEA, Vienna (1992). An important supplement to this work is the publication: Steps for Preparing Uranium Production Feasibility Studies: A Guidebook, IAEA-TECDOC-885, IAEA, Vienna (1996).

Recent IAEA activities related to the subject of this report include a Regional Training Course on Uranium Resource Inventories and Ore Reserve Calculation held in Changsha, China on 4–17 October 1997.

These consultancies may have contributed to the more complete and improved quality of resource reporting in the 1995 and 1997 editions of the Red Book: "Uranium — Resources, Production and Demand", prepared following the initiation of the meetings.

URANIUM SUPPLY ANALYSIS: EVOLUTION OF CONCEPTS

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Presented by V. Ruzicka

Abstract

Considerable effort has been expended during the last 15 years to develop improved methods of analysing current and future mineral supply, with the objectives of providing illustrations of mineral supply possibilities that are more meaningful and easily understood. Significant contributions toward these objectives have been made in the course of studies on world uranium supply, which took place in the 1970s prompted by concern about the future availability of mineral fuels. The Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD), and the International Atomic Energy Agency (IAEA) have played a key role in these efforts, through their biennial assessments of world uranium supply. There has been a pronounced shift in emphasis in the NEA/IAEA assessments away from resource estimates by themselves as a measure of supply, because of a growing awareness that, in isolation, resource estimates cannot provide a truly meaningful illustration of uranium availability. Indeed, resource estimates taken out of context can lead to false conclusions about resource adequacy. Successive NEA/IAEA studies have made increasing use of projections of production capability that show the possible availability of uranium from different categories of resources and production centres over specified time-frames. It is believed that such supply scenarios provide a much more meaningful illustration of uranium availability for both short and long-term planning purposes. As part of the effort to introduce such an approach to NEA/IAEA uranium supply analyses, the IAEA has prepared a manual which provides general guidelines for preparing projections of production capability. It is hoped that these efforts will contribute to a better understanding of the constraints on uranium supply and to the wider acceptance of projections of production capability as measures of resource adequacy.

1. INTRODUCTION

Considerable effort has been expended during the last 15 years to develop improved methods of analysing current and future mineral supply, with the objectives of providing illustrations of supply possibilities that are more meaningful and easily understood. Significant contributions toward these objectives have been made in the course of studies on the adequacy of the world's supply of mineral fuels in general, and of uranium in particular. The Nuclear Energy Agency (NEA) of the Organization for Economic Co-operation and Development (OECD) and the International Atomic Energy Agency (IAEA) have played a key role in these efforts, through their biennial assessments of world uranium supply.[1]

Following its first assessment of world uranium supply, published in August 1965, the NEA joined forces with the IAEA to broaden the scope of the assessments and to ensure the broadest possible geographic participation. The most recent of these joint reports, now commonly referred to as the Red Books, was published in December 1983 [2]. They have become known within the international nuclear community as the most authoritative references on the subject of world uranium supply, and have been relied upon as major source documents for studies on world energy supply carried out by the World Energy Conference [3, 4] and other international organizations. One of the more important special studies on the future of nuclear energy that relied on the Red Book was the International Nuclear Fuel Cycle Evaluation (INFCE) completed in 1979 [5].

The Red Book has evolved since 1965 to provide successively more comprehensive and meaningful assessments of world uranium supply. These assessments have reflected changing concepts and methods of analysing mineral supply, which have been developed by the national institutions that have supported the Red Book exercise over the years. This paper attempts to review briefly the evolution of conceptual thinking that is behind the type of production capability analysis that was used in the most recent Red Book, as an illustration of the world's currently perceived uranium supply capabilities.

2. RESOURCE CLASSIFICATION PRINCIPLES

Comprehensive resource estimates are the fundamental building blocks of any mineral supply analysis. However, it is essential that resource estimates be tied to a recognized system of classification in order to be viewed in proper perspective. The principles behind the most commonly used resource classification systems are illustrated in Figure 1.

This two-dimensional system provides an opportunity to show resource quantities in gradations of geological assurance (along the horizontal axis) and in gradations of economic attractiveness (along the vertical axis). The first deals with the level of confidence that the estimator has in the geological information that is available to him for making his estimates. The range in the level of confidence of the reported quantities is usually expressed by a series of descriptive terms, such as measured, indicated, inferred, etc., the distinctions between which are not always easy to define. The second dimension calls for judgments about mining and processing methods, capital and operating costs and possible markets, factors that can be equally elusive.

The dynamic nature of the mineral supply system is also illustrated in Figure 1. Over time, resources can flow from one category to another, as geological knowledge improves as a result of exploration efforts, and as economic factors vary such that there are changes in costs or prices associated with production of the resource. To the non-technical person, resources are often thought of as being finite and static. Because of this perception, such persons are not always aware of the effects of such things as changes in taxation and regulatory requirements and improvements in extractive technology on the dynamics of the system.

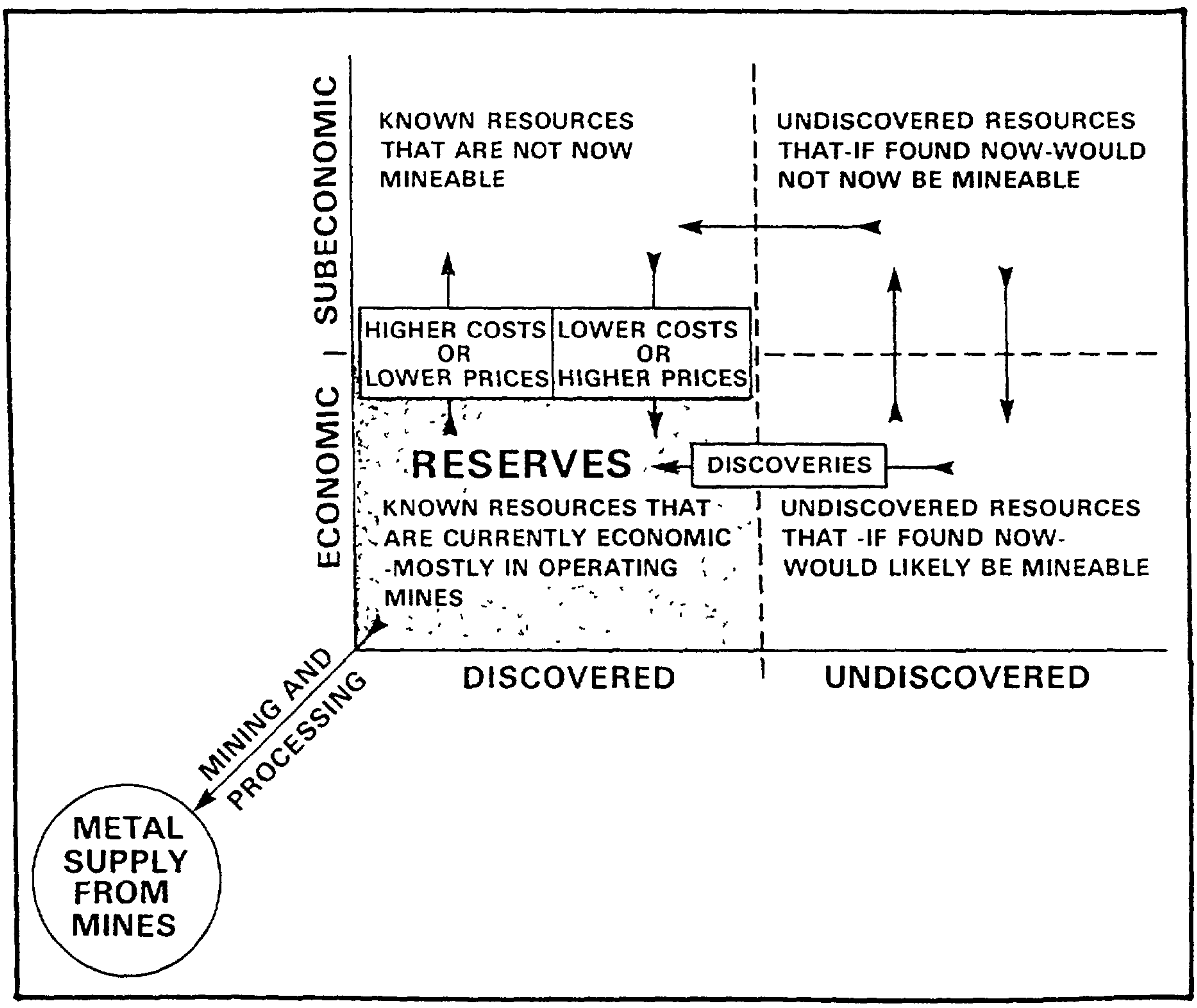

FIG. 1 The flow of resources over time.

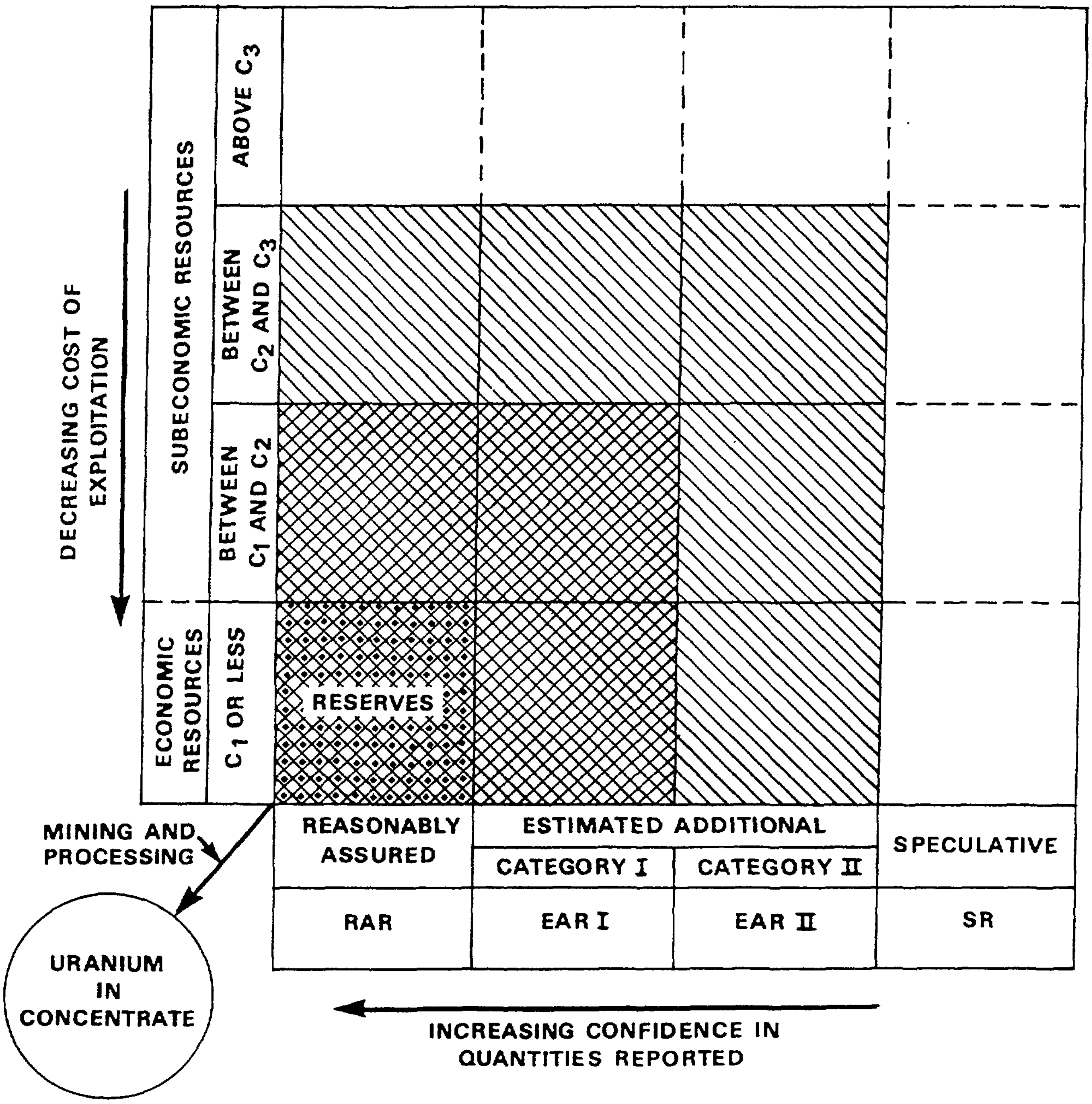

FIG. 2. NEA/IAEA uranium resource classification scheme.

These principles are embodied in the NEA/IAEA resource classification system, which is illustrated in Figure 2. The terms Reasonably Assured, Estimated Additional and Speculative Resources have become widely accepted internationally in mineral resource terminology. Very simply, Reasonably Assured Resources (RAR) are those contained in the best known part of a deposit, while Estimated Additional Resources (EAR) refer to less-well known material associated with the same deposit. In the case of EAR, a distinction is made between "discovered" and "undiscovered" material by means of a subdivision into Category I and II (EAR I and EAR II). Speculative Resources refer to resources contained in yet-to-be discovered deposits that are believed to exist in other geologically favourable areas. It is important to appreciate that the distinctions between these different categories are not precise, and that the geological assurance of existence criteria used by different estimators may vary.

NEA/IAEA	REASONABLY ASSURED		ESTIMATED ADDITIONAL I	ESTIMATED ADDITIONAL II	SPECULATIVE
EMR, CANADA	MEASURED	INDICATED	INFERRED	PROGNOSTICATED	SPECULATIVE
CEA, FRANCE	RESERVES I	RESERVES II	PERSPECTIVES I	PERSPECTIVES II	
USDOE	RESERVES		PROBABLE POTENTIAL		POSSIBLE AND SPECULATIVE POTENTIAL

FIG. 3. Approximate correlation of uranium resource terminology.

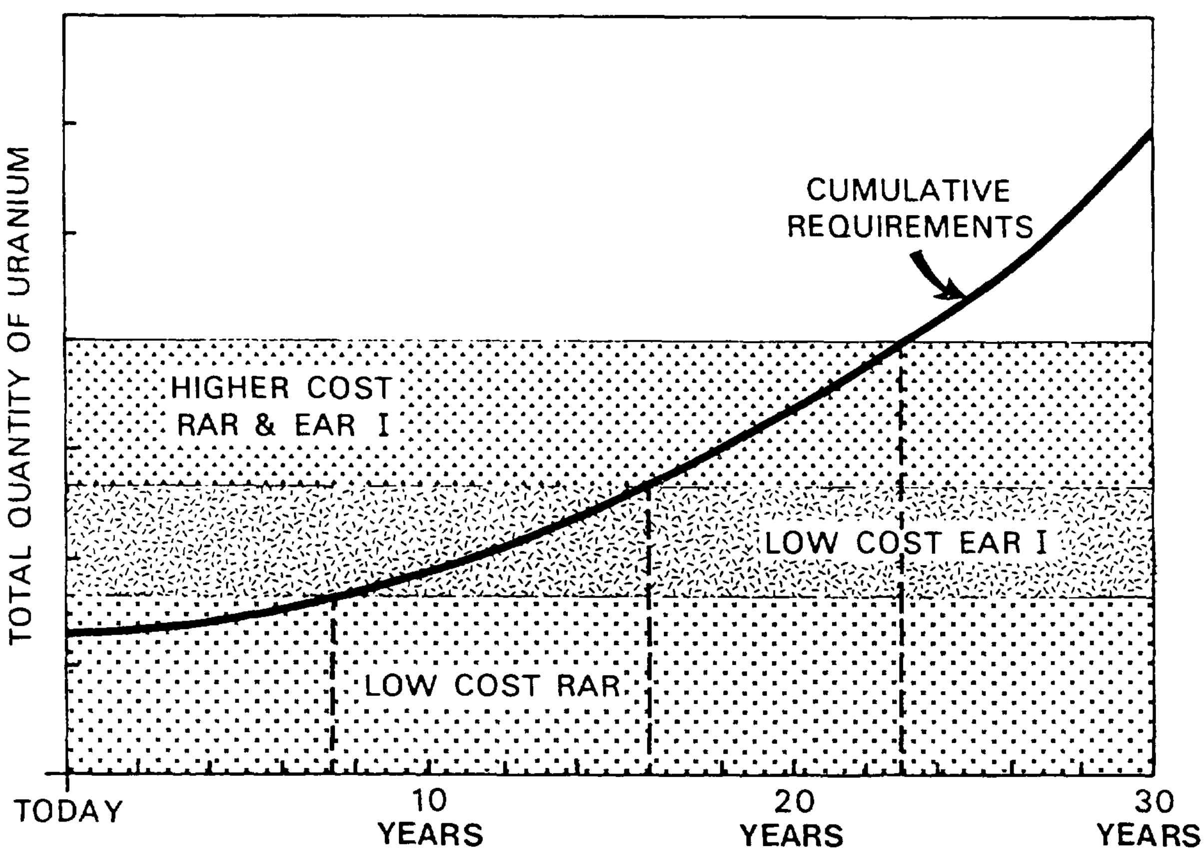

FIG. 4. Resource versus requirements.

For the economic subdivisions, the NEA/IAEA system employs the cost of production as its principal criterion. Although there is not a universal consensus about the total range of costs that should be considered when making these economic subdivisions, it is generally agreed that as many of the applicable costs as possible should be included. If all of the costs of producing a kilogram of uranium are included, then total cost should be equivalent to minimum acceptable price.

The term "Reserves" is generally restricted only to those RAR that are of economic interest at the time the estimate is made (i.e., they can be exploited at a profit). The NEA/IAEA scheme restricts the use of the term Reserves to the lowest cost RAR (i.e., recoverable at $US 80/kg U or less). Too often unwarranted emphasis is placed on the significance of the economic subdivisions. The distinctions between the cost categories are not absolutely sharp, nor can they be in view of the continued debate on the scope of the costs to be considered. The principal purpose of the NEA/IAEA's lowest subdivision, for example, has been simply to distinguish those resources that are of economic interest at the time of the assessment from those that are not.

The NEA/IAEA resource classification scheme equates very well with most schemes that are in common use, although terminology differs. Figure 3 illustrates the approximate correlation of terms used in Canada, France and the United States. It is perhaps useful to recall that the term Speculative Resources and its definition were not adopted by the NEA/IAEA until 1978, as a means of describing uranium discovery potential in Phase I of their International Uranium Resources Evaluation Project (IUREP). Great care was taken in the Phase I IUREP report to emphasize that the tonnages ascribed to the Speculative Resource category should be viewed simply as a qualitative measure of the current state of knowledge about areas that are geologically favourable for uranium discovery, and that they should not be used for nuclear power planning purposes. [6]

3. RESOURCE ESTIMATES AS MEASURES OF SUPPLY

Given a comprehensive set of resource estimates, categorized according to a recognized resource classification scheme, what do they tell us about future supply possibilities? Unfortunately, resource estimates in isolation tend to leave unanswered several essential availability-oriented questions. For example,

- Does the tonnage refer to in-place material or to recoverable material?
- What quantities are associated with existing production facilities and infrastructure?
- What quantities are producible, and at what rate, in the next few years? in the next decades?
- To what extent would production of another commodity lead to co-production of uranium?
- In the case of the EAR II and SR, what portion will actually be discovered, and at what rate?

It is frequently unclear whether a resource estimate represents an in-place quantity, or whether ore dilution, mining recoveries and ore processing losses have been accounted for. It is essential to distinguish between an IN-SITU estimate, an estimate of MINEABLE resources (i.e., uranium contained in mineable ore, after deductions to account for mining recovery and ore dilution), and an estimate of RECOVERABLE resources (i.e., uranium recoverable from mineable ore after deductions for expected ore processing losses). Although it is standard practice in many countries to express resource estimates in terms of mineable ore, it is the estimate of RECOVERABLE resources that is clearly important, and it is this latter concept that has been adopted in the NEA/IAEA resource classification system.

Analysis of uranium supply in early Red Books consisted primarily of a tabulation of resources by country according to the prescribed resource categories. The aggregate totals of these estimates

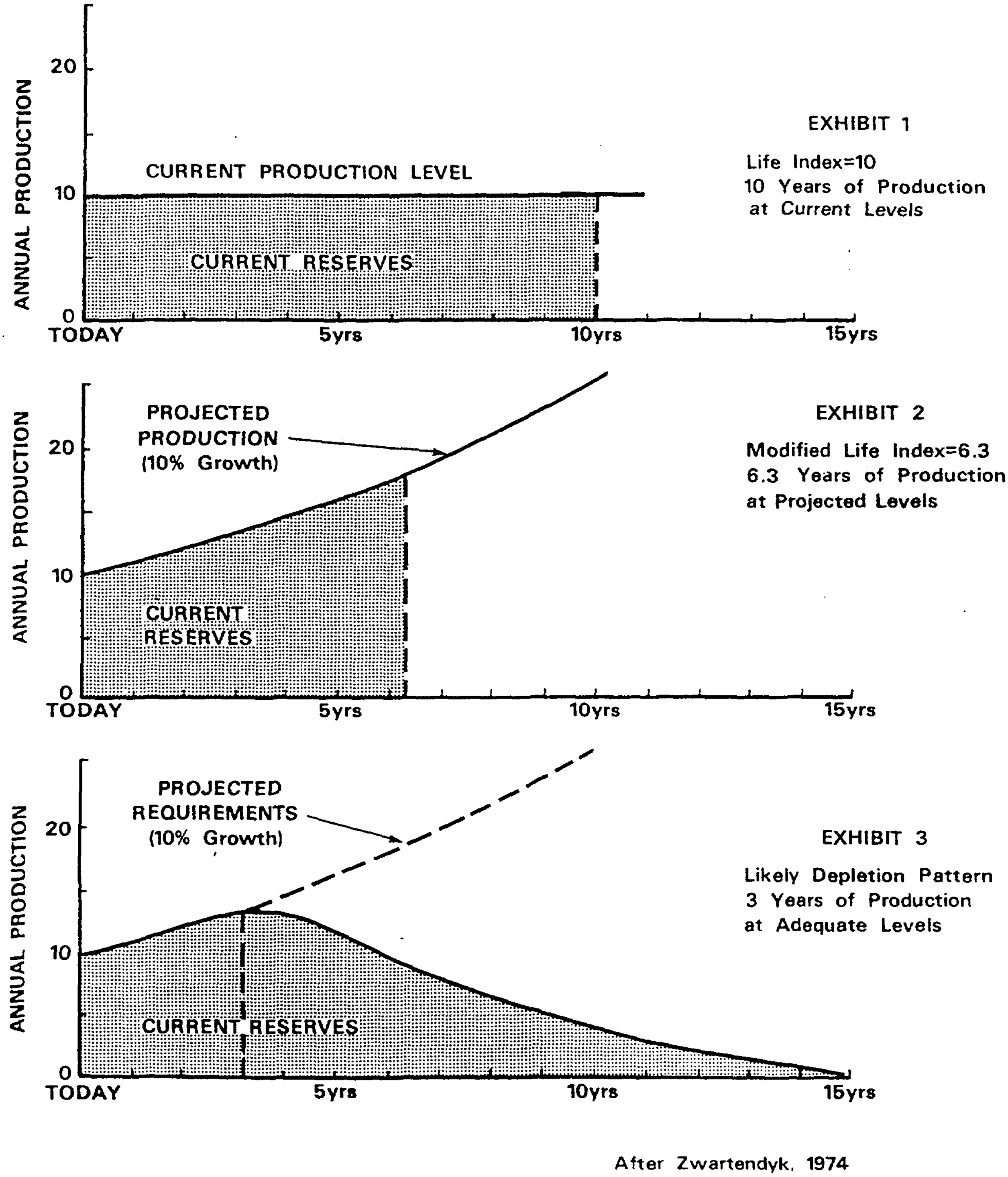

FIG. 5. The life index and its limitation.

were then compared directly with estimates of cumulative requirements as shown in Figure 4. The comparison seems to illustrate that low-cost RAR are sufficient to meet projected requirements for about seven years. Should low-cost EAR I and higher-cost RAR and EAR I be included, requirements could be met for 23 years. The comparison assumes that all of the resources can be made available over the projected time-frame, an assumption which can lead to a false conclusion about resource adequacy. Unfortunately, this technique continues to be used commonly by policy analysts, many of whom distort their conclusions still further by including in their comparisons estimates of undiscovered resources (i.e., EAR II and SR), without any regard to their discoverability or future availability.

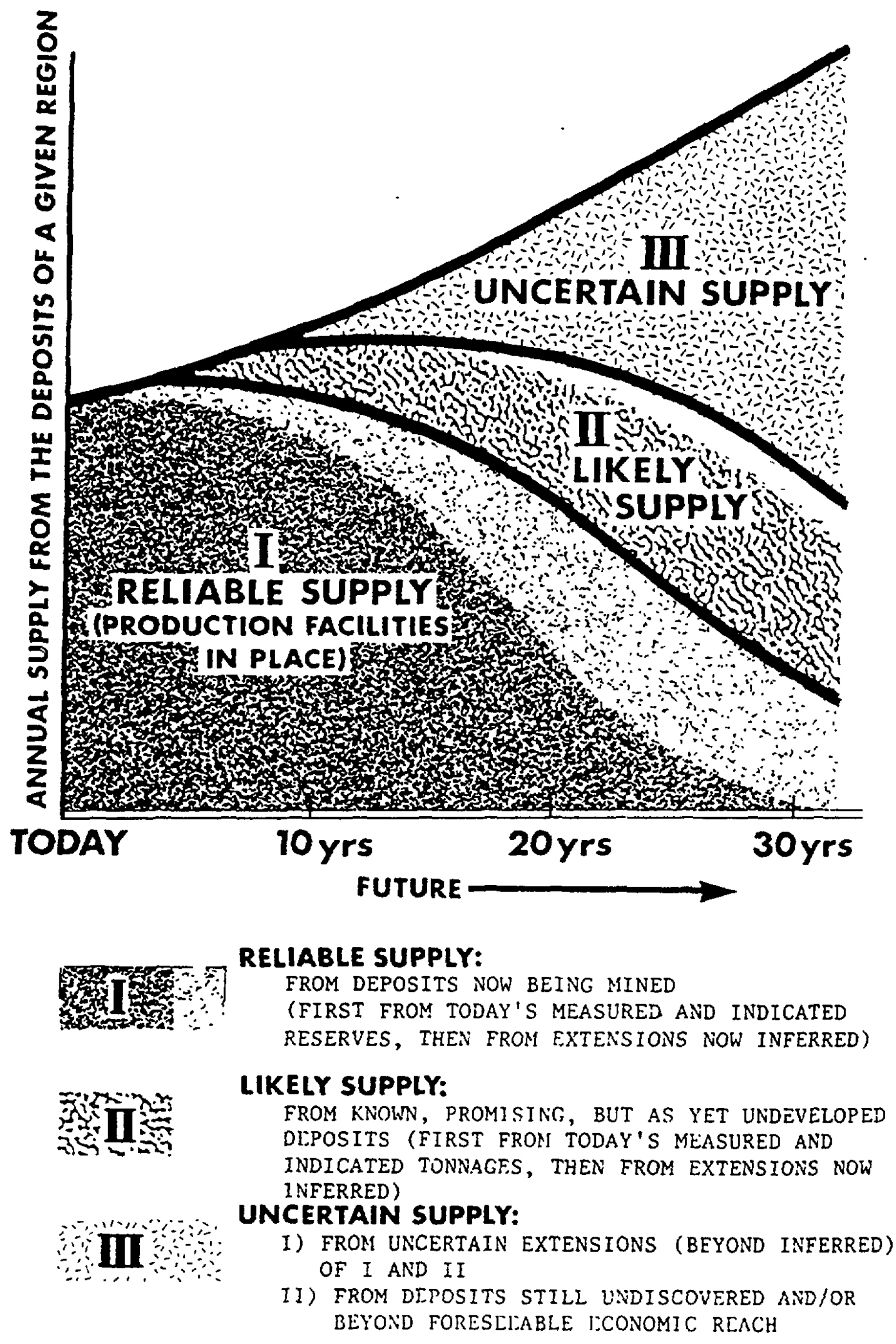

FIG. 6. Supply of a mineral commodity.

For many years the adequacy of reserves of a mineral commodity was measured using the "life index" principle. The life index of reserves is obtained by dividing a country's total reserves of a mineral commodity by the current annual rate of production. It is concluded, as illustrated in the top part of Figure 5, that current reserves are sufficient to last 10 years. Such an illustration ignores the facts that there are different extraction rates and life expectancies for individual operations, and that production levels may rise in response to increasing requirements. Neither the classic nor the modified version of the life index illustration depicted in the top two exhibits of Figure 5 bear much relation to the more likely pattern of reserve depletion shown in the third.

Although the Red Book series did not use the life index principle directly, it did develop a variation of it called the "forward-reserve" concept. By comparing current "reserve" levels with projected cumulative requirements for a future 10-year period, an attempt was made to judge the adequacy of reserve additions from one assessment to the next, and thus whether exploration activity levels were sufficient to maintain a viable industry. This technique also had its limitations and was phased out of Red Book studies by 1979.[1]

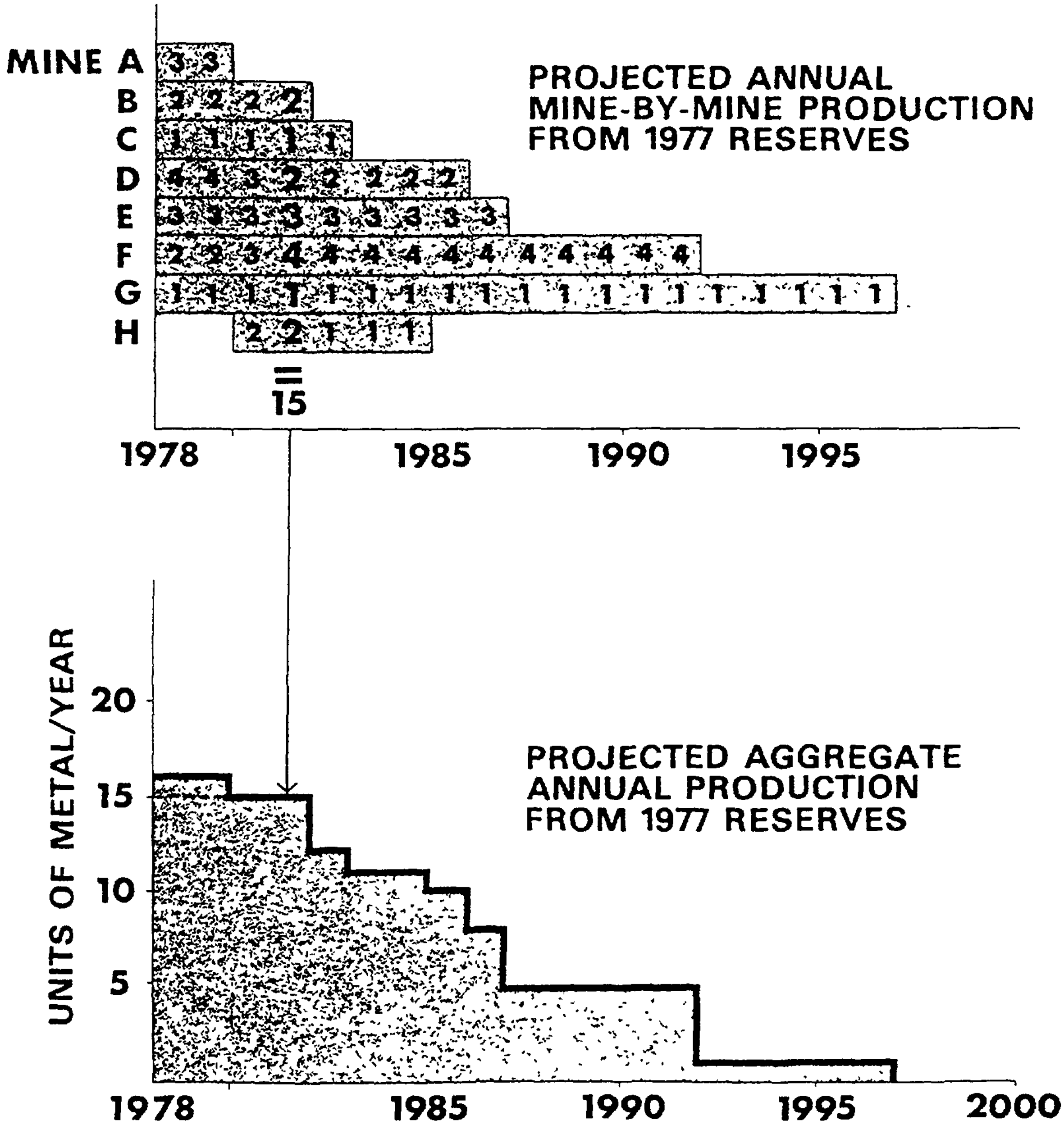

FIG. 7. Schematic derivation of a supply monitoring curve.

4. THE CONCEPT OF PRODUCTION CAPABILITY

Resource estimates by themselves, and techniques that use the life index principle or variations of it, therefore, are not very helpful in providing a measure of the life expectancy of reserves. Nor are they very helpful in illustrating the supply flow that could be expected from resources that are currently delineated or that will be developed over the coming years. However, plausible scenarios can be constructed to illustrate supply flows from different categories of resources and from different categories of production centres, using realistic assumptions about such things as ore processing plant capacities, recoveries, and lead times for ore body development and plant construction [Fig. 6]. Such scenarios, based on a mine-by-mine analysis, can provide a much more meaningful illustration of future supply possibilities than resource estimates by themselves. They can also be used to better demonstrate the reality that considerable exploration and development efforts and related investments of time, money and manpower are required to achieve future production goals [7].

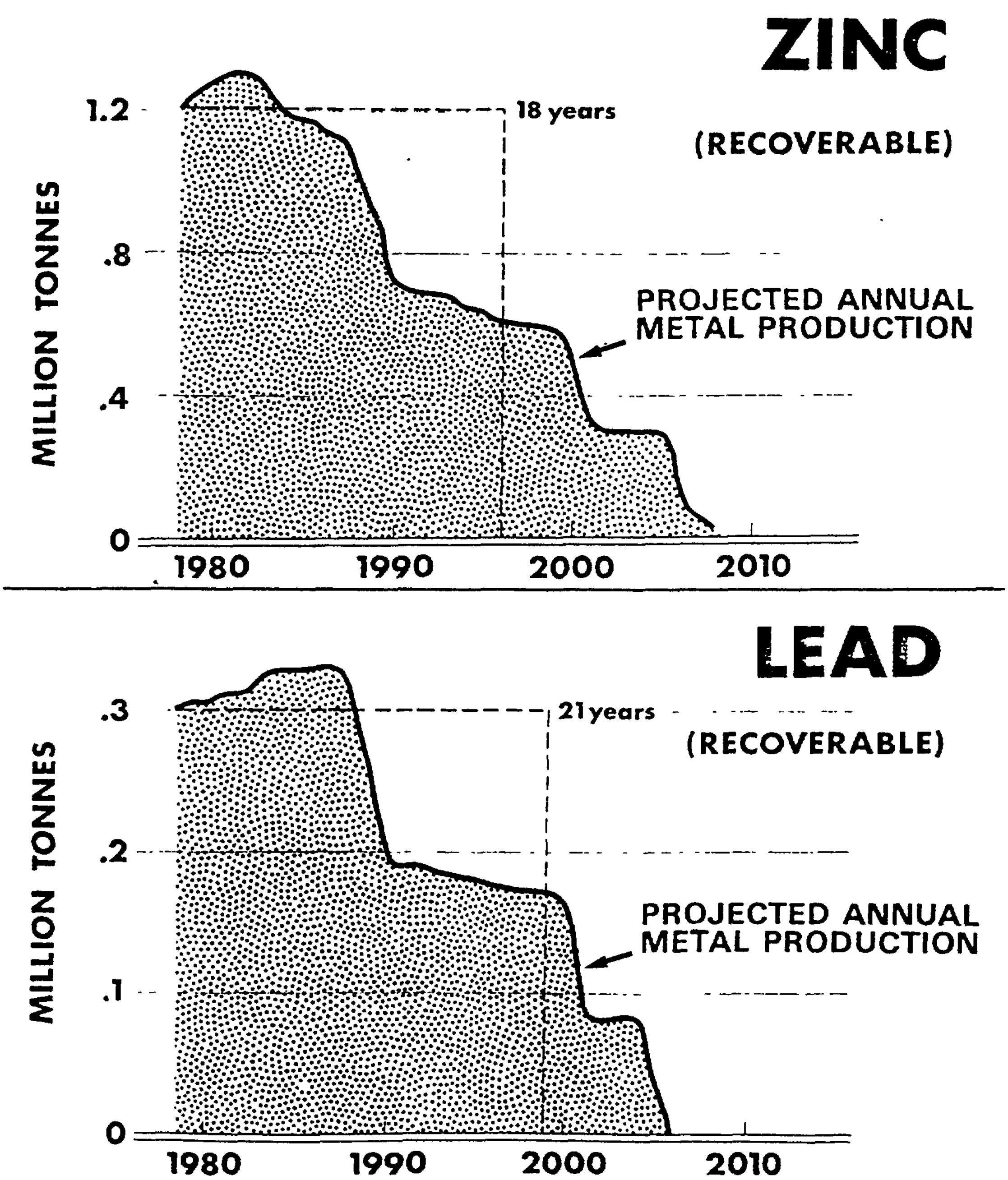

FIG. 8. Supply monitoring curves based on 1977 Canadian reserves.

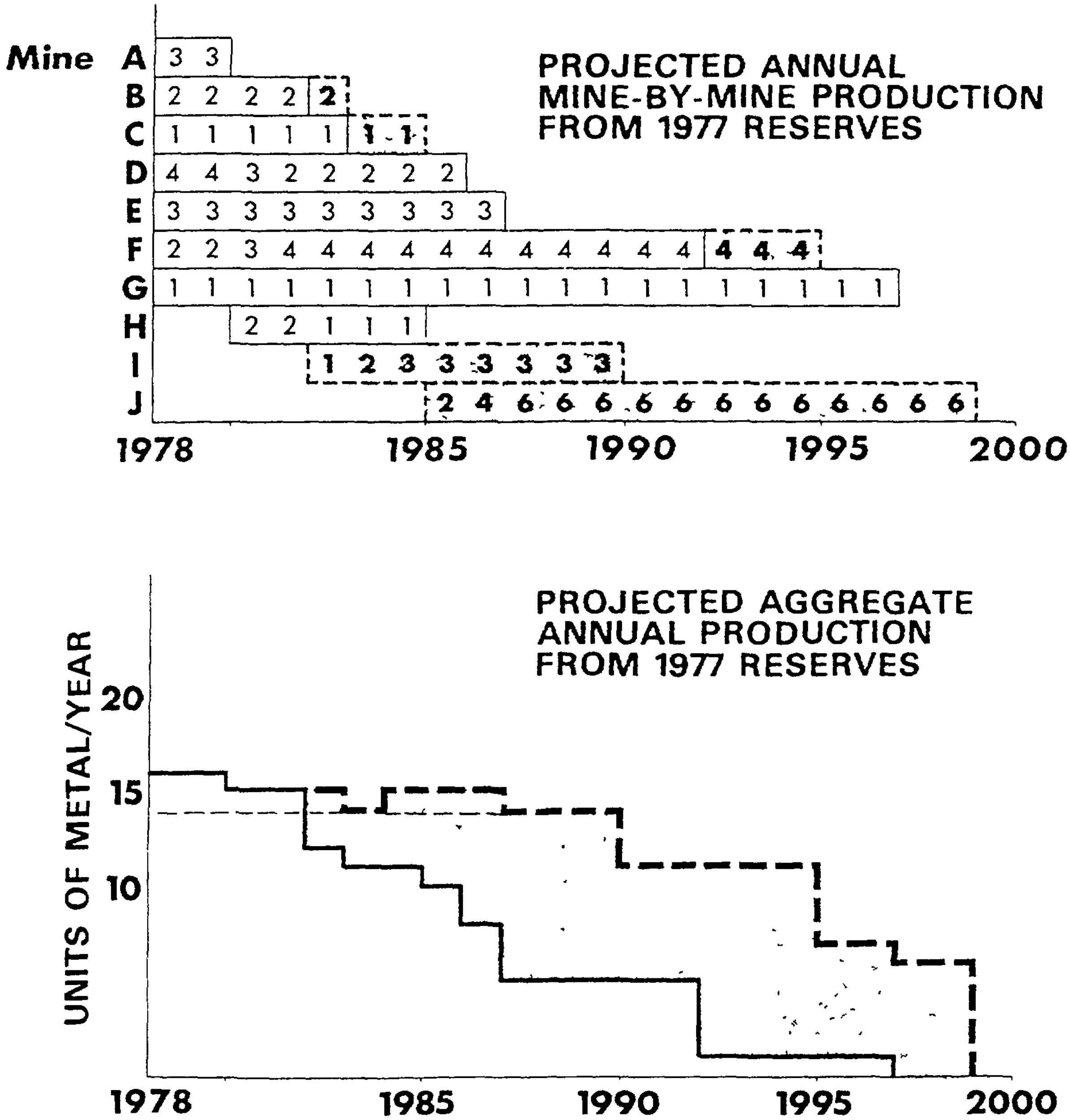

FIG. 9. Schematic derivation of projected future levels of production.

The principles behind the generation of these production capability curves are relatively simple and are shown schematically in Figure 7. The length of the horizontal bars in the upper part of the figure represents the years it would take to "mine-out" reserves of a metal at each of mines A to H, at annual production rates estimated for each year. This was a 1977 situation and, for simplicity, annual production rates are shown as multiples of some tonnage figure. For example, in 1978 mine F provided 2 units of production and plans were in place to raise this to 4 units per year by 1981. Cumulative production at the rates shown would exhaust the reserves by 1992. The lower part of Figure 7 shows the aggregate projected production capability for all of the mines A to H. For example, the sum of the outputs for 1982 would be 15 units.

Some real examples of such curves are shown in Figure 8 which illustrates expected supply flows from 1977 Canadian reserves of zinc and lead. In the case of zinc, the life index method (reserves to production ratio) had indicated that Canada's 1977 production level of 1.2 million tonnes of zinc could be maintained for 18 years. The production capability curve, on the other hand, shows that production would fall below 1977 levels after only 5 years, and would be half the 1977 level in 18 years, and that reserves would not be completely depleted for 30 years.

Figure 9 illustrates how the basic production capability curve can be built up from progressively less certain supply sources. The life of mines B, C and F can be extended by considering the inferred extensions to their ore bodies. In addition, two additional mines I and J, supported by reserves in "on-the-shelf" deposits, can be phased in to the supply scenario using appropriate assumptions about lead-times and ore processing plant capacities, etc. [8].

These techniques have been employed by Canada's Department of Energy, Mines and Resources (EMR) for a number of years to monitor the production capability, on an annual basis, of copper, zinc, lead, nickel, molybdenum, silver, gold, iron and asbestos [9]. Similar techniques are used in Canada's annual uranium supply assessment programme [10].

5. PRODUCTION CAPABILITY AND THE RED BOOK

The production capability concepts described briefly above have been incorporated into the NEA/IAEA's most recent Red Book. In addition, in an effort to encourage a wider use and acceptance of such techniques, guidelines for the preparation of projections of uranium production capability were published by the IAEA in July 1984 [11].

In order to systematize the preparation of production capability scenarios and to ensure that projections prepared by different countries can be aggregated into meaningful totals, the NEA/IAEA developed definitions for four classes of production centre. A production centre refers to "a production unit, consisting of one or more ore processing plants, one or more associated mines, and the resources that are tributary to them." The four classes of production centre are defined as follows:

(i) *EXISTING Production Centres* are those that currently exist in operational condition and include those plants which are closed down but which could be readily brought back into operation.

(ii) *COMMITTED Production Centres* are those that are either under construction or are firmly committed for construction.

(iii) *PLANNED Production Centres* are those that are planned, based on feasibility studies that are either completed or underway, but for which construction commitments have not yet been made. This class also includes those plants that are closed and which would require substantial expenditures to bring back into operation.

(iv) *PROSPECTIVE Production Centres* are those that could be supported by tributary RAR and EAR I, i.e. "known resources", but for which construction plans have not yet been made.

The object of the exercise is to make "an estimate of the level of production that could be practically and realistically achieved under favourable circumstances from the plant and facilities at any of the types of production centres described above, given the nature of the resources tributary to them." A number of basic pieces of information are required with respect to each production centre, as follows:

- Current resource estimates, by specified category and sequence of exploitation in the latest Red Book, only RAR and EAR I, recoverable at costs of $US130/kg U or less were to be used.)

- Start-up and expansion dates of the production units.

COMPANY: ______________________ PRODUCTION CENTRE (NAME): ______________________

LOCATION: ______________________ EXISTING ☐ PLANNED ☐ COMMITTED ☐ PROSPECTIVE ☐

1	2	3	4	5	6	7
YEAR	MINEABLE ORE (tonnes)	ORE PRODUCTION CAPABILITY (tonnes/year)	ORE PROCESSING CAPABILITY (tonnes/year)	GRADE OF ORE PROCESSED (kg U/tonne)	PROCESSING RECOVERY (%)	URANIUM PRODUCTION (kg U/year)

FIG. 10. Worksheet for production capability projection.

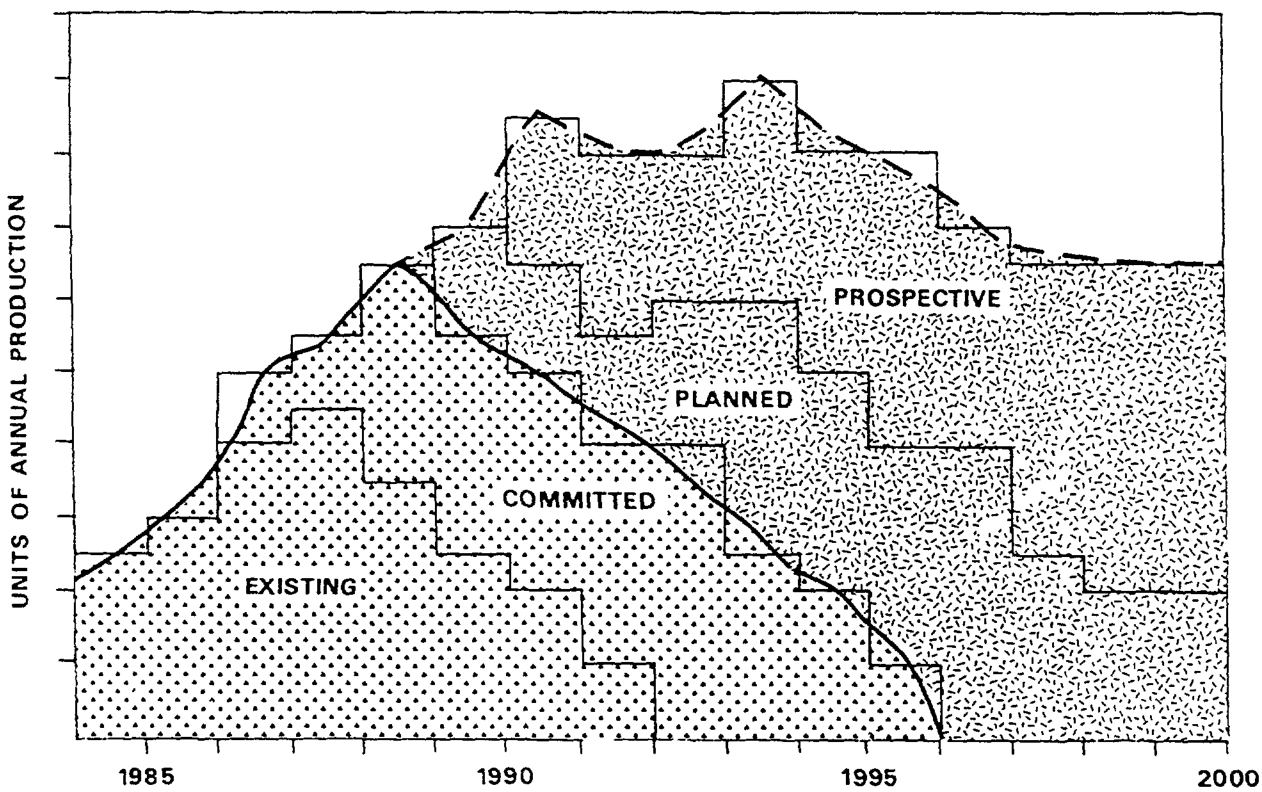

FIG. 11. Aggregation of production capability projections by production centre class.

- The daily ore processing rate (i.e , plant capacity)

- The number of operating days per year.

- The average grade of the ore that is fed to the ore processing plant.

- The average ore processing recoveries (i.e., it is usually easier to use resource estimates expressed in terms of mineable ore).

These pieces of information can be combined readily for each production centre with the help of a table like that shown in Figure 10, taken from the new IAEA manual on production capability [11] Variations of such a table may be more appropriate in individual cases, and where there is a very large number of production centres to analyse, computers would be helpful but are not essential.

Following a production-centre by production-centre analysis, the results can be aggregated and grouped according to a variety of desired combinations. Figure 11 demonstrates, schematically, the way national production capability projections were aggregated in the most recent Red Book. The objective was to prepare an illustration of two possible levels of future world uranium production capability, which could be supported by resources contained in known deposits. The lower curve, constructed by aggregating production capability estimates for all EXISTING and COMMITTED

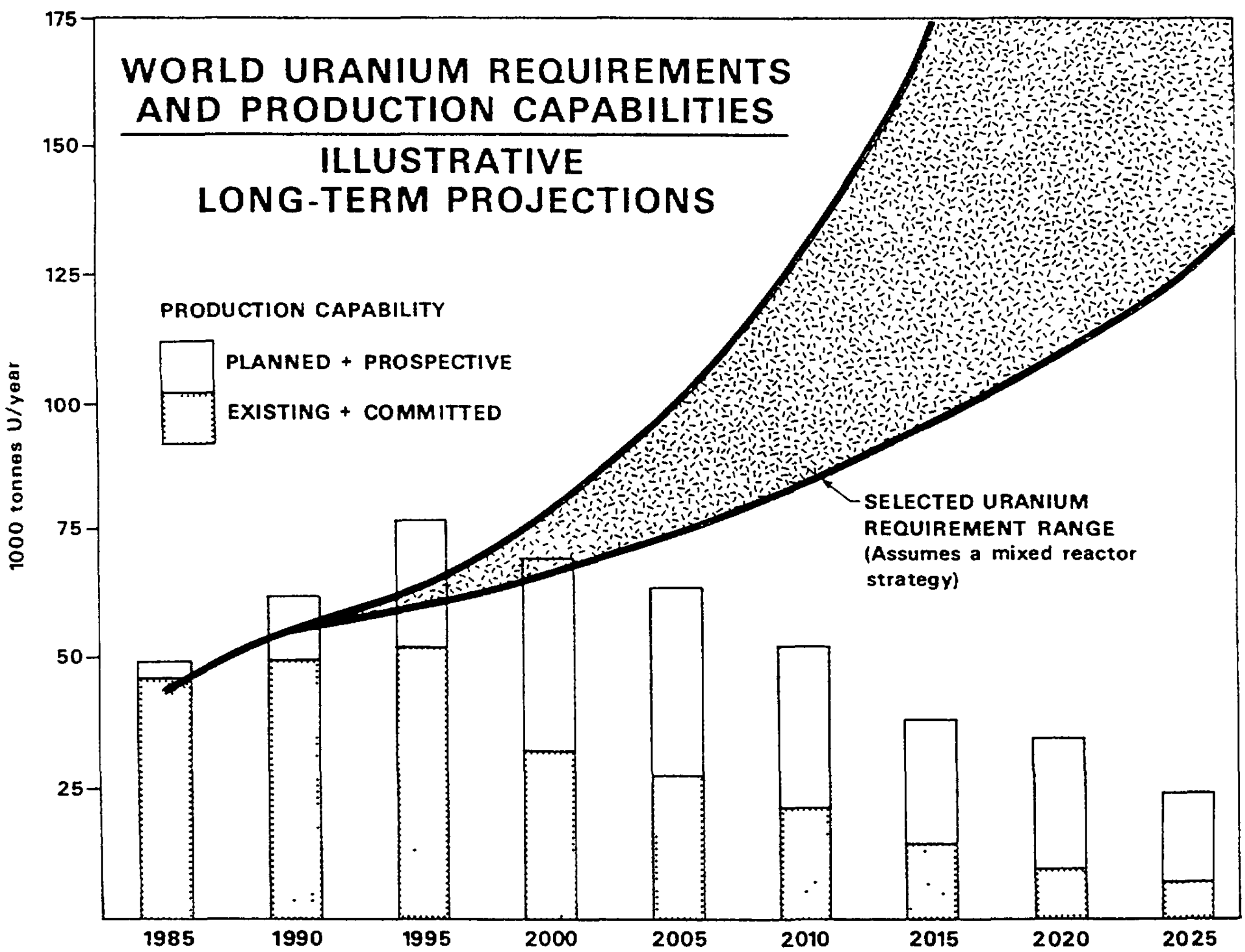

FIG 12 World uranium requirements and production capabilities (illustrative long-term projections)

production centres, illustrates a uranium supply level that can be counted upon with a fairly high degree of certainty. The upper curve, which includes the production capability possible from PLANNED and PROSPECTIVE production centres, illustrates that a higher level of production could be achieved if required, and given appropriate incentives. This two-scenario approach shows that there is a broad range of production possibilities depending on how the uranium market actually develops.

Figure 12 presents the results of the latest Red Book production capability analysis, in comparison with an illustrative range of projected world[1] uranium requirements. The figure shows that, while sufficient production capability is committed at the moment, some additional production would have to be put in place by the early 1990s to meet the projected requirements. Beyond the turn of the century, even with the uncommitted production centres that could be supported by "on-the-shelf" deposits, uranium could not be made available at rates sufficient to meet the illustrated requirements. Clearly, new production centres would be required and further discoveries would have to be forthcoming to support them. The figure also illustrates how the RAR and EAR I associated with the respective production centres would be depleted, assuming optimum conditions and no new discoveries.

6. CONCLUSION

There has been a growing awareness that resource estimates, in isolation, cannot provide a truly meaningful measure of mineral supply. Unfortunately, they leave unanswered too many availability-related questions. These limitations have led to increased efforts to develop techniques for projecting production levels that could be supported by specified categories of resources and production centres, given varying assumptions. Such projections rely on a production-centre by production-centre analysis, and are normally aggregated according to successively less assured classes of production centres, to provide several possible mineral supply scenarios. Such techniques are being used effectively in a growing number of national uranium supply assessment programs, and have been adopted in recent NEA/IAEA Red Books as a more meaningful way of illustrating future uranium availability. It is anticipated that such projection methodologies will benefit from continued development and that the production capability scenario approach will become increasingly popular as a method of illustrating future uranium supply possibilities.

ACKNOWLEDGEMENTS

Particular credit is due to Jan Zwartendyk of EMR Canada's Mineral Policy Sector, whose inspiration and clarity of thought have contributed in large measure to the advancement of the type of mineral supply analysis techniques described in this paper. His continued support of Canadian efforts within NEA/IAEA fora to promote the use of such techniques is gratefully acknowledged.

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THE WAYS OF HARMONIZATION OF URANIUM RESOURCES ACCOUNTING SYSTEMS ON A GLOBAL SCALE

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Abstract

Resource classification systems used today in different countries make reference to the same principals: geological variability, commercial importance and level of preparedness for production. However, some countries with mining industries and established traditions use different classifications that are difficult to harmonize. To assist in developing a common international classification four issues are proposed for discussion: 1) existence of production facilities for producing resources; 2) need for low production cost categories compatible with current market prices; 3) specifying the degree of accuracy for various categories of resources and 4) in situ versus recoverable resource estimates. Based on these concepts revisions are proposed to the IAEA uranium classification system. Examples are also given of resource classifications for the Streltzovskoe deposit, Krasnokamensk.

The current period can be described as the time of growing international economic integration. Nuclear power industry is one of vital areas, where such integration is especially needed. The issue of uranium mineral resources availability is very important for prognostication of nuclear power production. Uranium is a rare element and its earthy stock more limited then those of other energy sources. The available produced uranium is in storages and military stockpiles ready for conversion — the amounts are considerable, but limited.

Different countries of the world apply different classifications of mineral resources, but based on the same principles. Three principles are used: geological variability, commercial importance and preparedness of deposits and resources for production. The categories and groups within such classifications are very close to each other, although differ in their number and denominations. Each country with a developed mining industry follows well established traditions in studying mineral deposits accounting their resources and describing them as categories and groups within adopted classifications. This is a main difficulty in reducing the categories and groups from different classifications to objective uniform criteria.

However, an experienced geologist, when considering the data for any particular project, can define with certainty how the resources calculated for any category meet his traditional classification. They tried more than once to establish a uniform classification of mineral resources. Even by the end of the 70s IAEA experts offered a draft International Classification. However, there is a little hope of any country adopting this or any other international document instead of their national classification.

We believe it would be more practical first of all to find some common principles in classifications. Below there are four points for discussion:

1. Most of the classifications use the principle of two-dimensional matrix with two inputs: variability (degree of exploration) of the resources and their economic volume. However, it is advisable to account the third factor as well: the readiness of the resources for production. Indeed, in marketing forecasts it is necessary to take into account the real possibility of mineral supplies from a particular source within a specific time, hence it is very important to know if established production facilities exist at the project site.

   Certainly such factors are taken into account in all countries. In Russia, for example, the State system of resource account provides a breakdown account for deposits with a mine in operation, deposits, where no mine is built, but all information for technical design is ready and deposits with geological assessment only, although such subdivisions are not stipulated by the existing classification. This third factor is necessary for accounting.

2. All Classifications stipulate economic subdivisions. The criteria could be qualitative (economic/non-economic) or quantitative, with certain cost limits established. The IAEA Red Book applies the quantitative approach. In this case, they face an additional matter of number and specific values of price limits — for instance the adviseability of using price categories below $80 per kg.

   The current uranium market calls for additional categories of cheap resources and quantitative price categories in general. The Russian classification of mineral resources does not stipulate price categories. However, economic calculations of probable production costs are obligatory for deposit estimates and for putting the resources into the State Register. The appropriate data can be obtained and submitted for the Red Book.

3. None of the current classifications stipulate the degree of accuracy and variability for various categories of resources. Nevertheless, this is a matter of permanent discussions. It is very difficult to assess the practical accuracy of resource estimates and limiting values for a specific body. In any case, it is clear that accuracy and variability is higher for top categories and lower for low categories. One can assume this accuracy about the same for the top category in all classifications. We would not recommend to establish a fixed value of this accuracy for each category as an obligatory parameter of estimated resource.

   Experts in Russia are of the opinion that mistakes in fixing ore boundary position are more important practically than mistakes in number of resources. Experiments with computer models showed that mistakes in fixing the boundary position are lower than 15% for the B-category, lower than 30% for the C-l category and more than 30–50% for the C-2 category of Russian classification.

4. By and large, there are two approaches to the resource account: resources in situ or recoverable resources, i.e. minus expected production losses. We believe that all resources must be estimated in situ. Firstly, the amount of losses in a standard mining cycle, at least for uranium, is comparatively low, because there are different methods of decreasing them: radiometric sorting, heap leaching and block leaching. Secondly, as Russian experience shows, the actual deposit resources often rise during production size mineworks reveal additional ore bodies. This increment covers not only the production losses, but, sometimes, surpasses the production as well. For instance, after the initial 15 years of operation, the Streltzovsky cluster deposits showed the remaining resources practically equal to the initial estimate. Systematic deduction of expected losses in global estimates will result in underrated actual resources of uranium.

In attempts to solve the problem of Uranium International Resources Classification, it is necessary, first of all, to outline distinctly the general goal of such a classification. Apparently, such classification should provide the information of known resources on global scale to prognosticate the availability of raw materials for nuclear power industry. Then, we must accept, that a uniform international system for the resources accounting, functioning both as a national and international system is unrealistic for the near future.

To collect information from individual countries the IAEA has one instrument — a questionnaire. Of course, the questionnaire, must follow a uniform classification, adopted by the IAEA. However, this classification should not necessarily coincide with national classifications. Only the national expert, in charge of the questionnaire programme, can adequately translate the information from the national classification into the terms of the uniform classification, since only this expert possesses a specific knowledge of the deposits estimated. At the same time, the authors have to check the submitted data, even if they establish a uniform right approach for comparison of the classifications.

		RAR		EAR-I		EAR-II(SR)	
		Mining	In situ leaching	Mining	In situ leaching	Mining	In situ leaching
<25$ per kg	Working factory						
	Absent factory						
25-40$ per kg	Conserved factory						
	Absent factory						
40-80$ per kg	Conserved factory						
	Absent factory						

FIG. 1. Modified IAEA uranium resource classification showing options for making different forecasts.

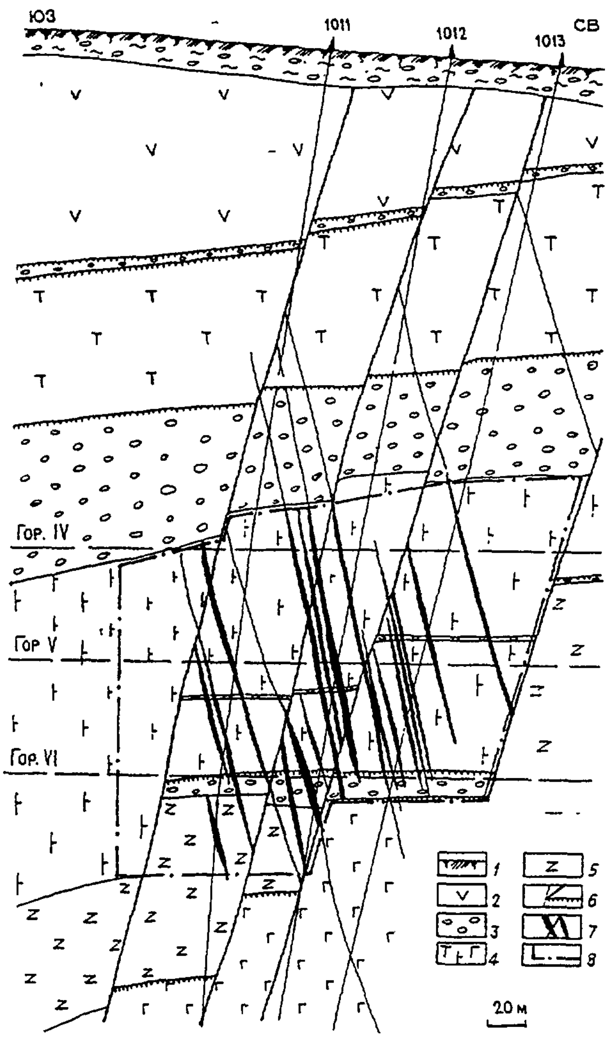

FIG. 2. Cross Section 112 of Streltzovskoe deposit in the pre-feasibility stage: the category of resources is C2.

1 drift
2 felsite
3 conglomerate
4 various basalts
5 dacite
6 fracture
7 intersection of orebodies by drill holes
8 block boundary of calculated resources

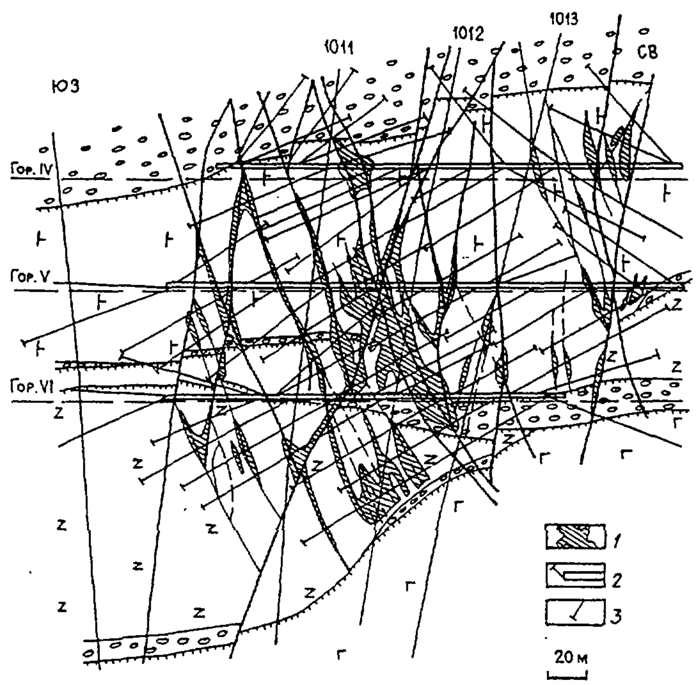

FIG. 3. Cross section 112 of Streltzovskoe deposit in the feasibility stage: the category of resources is C1.

1 ore
2 mining tunnel
3 drill hole

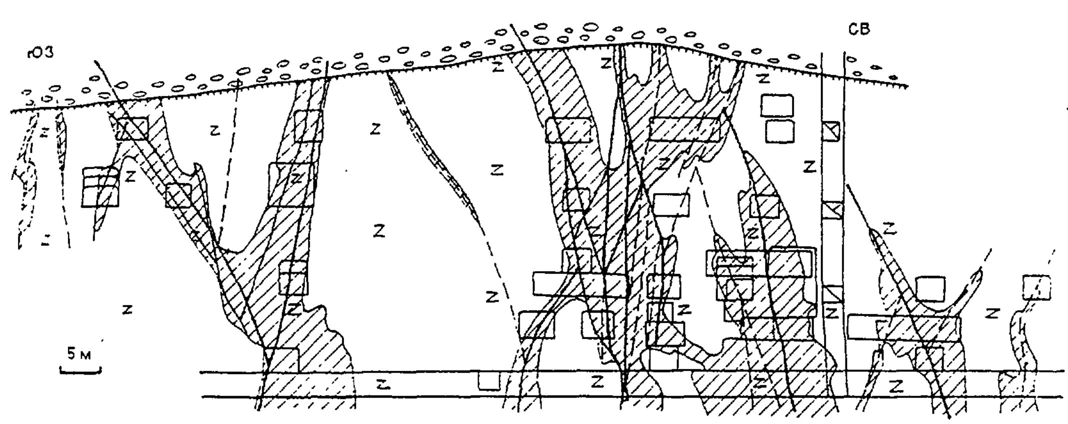

FIG. 4. Cross section 112 (Streltzovskoe deposit) shown in Figs 2 and 3, in the mining stage: the resource category is B (see Figs 2 and 3 for legend).

In this connection it hardly makes sense to try further to set up a uniform comparison chart for currently used classifications. It is more important to improve a global system of uranium resources accounting on the basis of the Red Book classification. We believe it is necessary and sufficient to retain only three subdivisions (by variability): RAR, EAR-I and EAR-II (or SR). Then, accounting the speculative resources for expected deposits (unknown) is at this stage unfeasible.

It is necessary to account separately the resources of deposits with mines functioning, conserved or absent. We believe that it is necessary to account separately the resources available for mining and in situ leaching using wells, since for the latter the new enterprises or the development of existing facilities comes much faster and cheaper.

Figure 1 shows the diagram of dependence between uranium content and cost of production. The great different between the lines stipulates the primary significant of in situ leaching deposits for their low costs.

Apparently, modifications in economic categories of resources are unavoidable: new categories of $25 and $50 (or near) must be introduced. The category of $50–$80 shall be retained, but the $80–$130 should be cancelled.

The data on ore reserves average metal content seam to be redundant, because in the same countries the production is based on in situ leaching, where metal content is much lower the term "ore" makes no sense, but the feasibility factor of production is extremely high.

All possible classification is shown in Figure 1. In this scheme we tried to show the possibility of using different resource categories for different forecasts. So, the dark shade means resources for short term prognostication, while the market price is invariable. The lighter shading is for resources for long term prognostication, if the market price is higher etc.

We suggest as a possible way for further improvement of international system of uranium resources account a unified method for expert decisions, when certifying the resources of specific deposits as a category in various classifications. We believe, that to this end it would be useful to have an international reference album, compiled by the International Experts Group as a part of IAEA research programme.

The album shall illustrate the cases when resources of the same deposit fit several categories in different classifications most frequently applied. Typical deposits in Russia, Canada, Australia and other countries could be used for examples.

Some pictures from Streltzovskoe deposit, showing the ore bodies, exploring as C-2, C-l and B-category are in Figs. 2 to 4. From one of them you can see the effect of increasing of resources by C-2 to C-l category.

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THE COMPARISON OF THE IAEA URANIUM RESOURCES CLASSIFICATION WITH THE PROJECT OF MINERAL RESERVES AND RESOURCES CLASSIFICATION OF THE STATE MINERAL FUND OF UKRAINE
(Summary)

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XA9847830

The existing IAEA uranium resources classification includes long-term experience of international cooperation in the field of creation of mineral raw base for nuclear engineering. This classification was being improved during long time when uranium supply and demand fluctuated and continue to fluctuate in accordance with market situation. Therefore, it is a real matter of course that during composing the Classification of Mineral Reserves and Resources of the State Mineral Fund of Ukraine, specialists tried to take into consideration the best experience in world practice including the existing IAEA uranium resources classification.

Experts of Kirovgeology using the IAEA classification during cooperation with the Agency note with satisfaction that the project of mineral reserves and resources classification of Ukraine is very similar to the IAEA uranium resources classification. It can be seen during comparing attached diagrams of the IAEA uranium resources classification and the project of mineral reserves and resources classification of Ukraine. Approaches to division of resources according to their geological investigation are very similar in both cases.

Estimated Additional Resources — Category II (EAR-II) and Speculative Resources (SR) of the IAEA classification relate to "undiscovered" resources like as perspective and prognosticated resources in the project of Ukrainian classification.

Reasonably Assured Resources (RAR) and Estimated Additional Resources — Category I (EAR-I) of the IAEA classification relate to "identified" resources like as explored and preliminarily estimated reserves in the project of Ukrainian classification. Both systems are based on existing drilling cross-sections or mining tests with different degree of extrapolation from real data.

Reasonably Assured Resources (RAR) conform almost exactly to explored reserves of Ukrainian classification both are based on concrete orebody cross-sections.

Estimated Additional Resources — Category I (EAR-I) are identical to preliminarily estimated reserves in the project of Ukrainian classification because they are based on extrapolation of real drilling cross-section data. There is only a difference that the IAEA uranium resources classification (RAR and EAR-I) determines quantity of recoverable uranium but the project of Ukrainian classification proposes definition as resources in situ, so recoverable resources. In our opinion during transition to market economy it is necessary because the state property on mineral resources will exist for a long time.

Estimated Additional Resources — Category II (EAR-II) of the IAEA classification are corresponded with perspective resources in the project of Ukrainian classification. Both are based on indirect indications "within areas of mineralization with known deposits". Such definition of the IAEA classification concurs with the project of Ukrainian classification where perspective resources are connected with anomalies which origin is determined within known ore areas.

Speculative Resources (SR) of the IAEA classification are determined by geological extrapolation which is based on geological conditions of area, i.e. on positive geological, tectonic and other prerequisites foreseen by the project of Ukrainian classification.

USSR		C_1	C_2+P_1	P_2	P_3
Ukraine, 1996		Explored Reserves	Preliminarily Estimated Reserves	Perspective Resources	Prognosed Resources
Outbalance Reserves	More than US$130/kg U	II (221) I (211)		Usually don't marked	
Conditionally Balance Reserves	US$80-130/kg U	I (211)	II (222)		
Balance Reserves	US$40-80/kg U	II (121)	III (132)	III (333)	0 (304)
	Up to US$40/kg U	I (111)	II (122)	0 (303)	

Decreasing economic attractiveness

Decreasing confidence in estimates

Decreasing technical-economical studying

0 GEE is not carried out
III GEE-3
II GEE-2
I GEE-1

(111) - Code of taxon

1 - Economical importance
2 - Technical-economical studying
3 - Geological studying
(for reserves evaluation)

Figure 1. Classification of mineral reserves and resources of the State Mineral Fund of Ukraine (1996)

The project of Ukrainian classification is based only on deposits of known geological-economical types. It is similar to division of deposits into "traditional" and "non--traditional" indicated in Red Book. It is possible only in case if it will be included not 7 types but 11 types of deposits in "traditional" deposits.

An advance made by IAEA is division of resources according to cost ranges of their recovery instead of traditional division into "balance" and "sub-balance" as in all other classifications. However, it is foreseen in the project of Ukrainian classification that groups of resources according to cost price of their mining and processing will be established in instruction of classification's application to the specific mineral deposit. Doubtless, the instruction of classification's application to the certain mineral deposit must take into account the experience of the IAEA Red Book.

At present probably it can be considered that balance uranium resources of Ukrainian classification cover resources at cost of up to US$80/kg U, conditionally balance resources — up to US$130/kg U, outbalance resources more than US$130/kg U.

Thus, in our opinion, the Ukrainian project of classification of mineral resources and reserves takes into consideration the best aspects of the IAEA uranium resources classification. The using division of classes of mineral resources and reserves according to their investigation and trustworthiness is approximated to the IAEA classification as much as possible.

According to technical-economical and commercial investigation of resources as well as development of the deposit to its exploitation the division of resources/reserves is introduced in the project of Ukrainian classification. It must bring requirements of instruction nearer to market conditions.

SOME COMMENTS ON THE DEVELOPMENT OF A MORE UNIFORM AND MEANINGFUL CLASSIFICATION OF URANIUM RESOURCES

(Summary)

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Until now, CIS countries still use the classification of reserves for metallic minerals which were used in the former USSR. In Russia, as well as in Kazakhstan, the Ministries of Geology are preparing a new classification which differ slightly from the present one. It is understood that with the exception the one used in the former USSR, other classifications of reserves are not oppose to the one accepted by IAEA.

The classification which is being used in Kazakhstan and Russia, and perhaps also in Uzbekistan, the category of reserves and resources for deposits of sandstone types which are being exploited by in situ leaching method are not comparable to the deposits of hydrothermal origin which are being mined by conventional method. Therefore, in the proposed comparative table of resources classification (Table I) it seems advisable to shift the scale of resources categories and reserves for deposits that can be produced by ISL method one column to the left.

TABLE I. URANIUM RESOURCES CLASSIFICATION

		CATEGORIES			
IAEA		RAR		EAR-I	EAR-II
CIS	Traditional	B	C1	C2	P1
	ISL	C1	C2	P1	P2

Foreign experts who are engaged in extraction of uranium by ISL methods, in re-evaluating the reserves of Kazakhstan sandstone deposits, noted the need to differentiate the reserves for different types of deposits.

For CIS countries, particularly in recent years, reliable economical evaluation is difficult. It is caused by production slumps in most commodities and economical instability, which lead to unrestrained increase of prices for materials and fossil fuel. Unpredictable depreciation of the local currency resulted in a marked and uncontrolled slump of exchange value against the dollar. Cost divisions of resources for the groups less than US\$40, US\$40–\$80, US\$80–\$130 and US\$130–\$250 are not related to the current world prices for uranium in the spot market. Under the present spot prices, in Kazakhstan, only extraction of uranium by ISL method is economically viable.

Considering the two dimensional table of resources used in the Red Book Questionnaire for 1995, one can see that the terms used are not sufficiently informative. One should think that the names of the categories should have a more distinctive meaning. The definition of Reasonably Assured Resources (RAR) is telling about the matter of this category. For the characteristics of Estimated Additional Resources categories I and II (EAR-I and EAR-II) they become meaningful only after the detailed explanation. The most meaningful names of categories are those used in Canada, Germany, the U.S.A.

In CIS countries, the classifications of resources and reserves is common for all metallic minerals. For the uranium reserves in the former USSR there was an instruction for entering additions into the generally accepted classes, but without changing the nature and names of the categories. New and unified uranium resources classification will differ more significantly from the old one (in CIS countries). One should note that in CIS countries the resources of all minerals, including uranium, are subject to formal approval by the State Commission on Reserves.

In CIS countries there are two conceptions: reserves and resources. Each of these groups has categories. This results in a confusion of terminology application. In the rest of the world, perhaps excluding France, there is only one term: "Resources" with common scale of categories. It seems the last approach is more logical and rational. In conclusion we are of the opinion that it is necessary to finish the process of world uranium resources unification as soon as possible.

THE CLASSIFICATION, COST CATEGORIES AND THE SYSTEM OF ACCOUNTING FOR URANIUM RESOURCES IN THE RUSSIAN FEDERATION AND CIS COUNTRIES

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Abstract

In 1992 the uranium resource classification systems of Kazakhstan, Russian Federation, Ukraine and Uzbekistan are the same as the system used in the former Soviet Union. The Soviet Union adopted this system as a state law in 1981. Under this system resources are reported as "in situ" with no allowance for mining or milling losses and resource depletion. The resources are subdivided according to the degree of exploration and economic value. The classification system divides resources into 7 categories. This includes 3 categories of explored resources (A, B, and C); one of preliminary assessment (C2); and 3 as prognosticated or speculative (P1, P2 and P3). Further analyses and classification is used to determine the readiness for production. This system is used to define the inventory or "State Balance". Examples are given for classifying vein-type and rollfront-type sandstone hosted deposits. A discussion of how resources are classified by cost category is given. It is stated, however, that any coincidence between the cost categories used in the former Soviet Union and the cost categories of the IAEA system are "purely accidental".

RESOURCE CATEGORIES

In all the countries of the former USSR possessing uranium resources (Russia, the Ukraine, Kazakhstan and Uzbekistan) at present they keep the mineral resources inventory system as used in the USSR. This system is based on the State Classification Standards for mineral resources adopted in the ex-USSR in 1981 as a State Law. According to this Classification the solid mineral resources are reported as in situ disregarding production losses and depletion.

The resources under the Classification are subdivided according to the degree of exploration and economic value. Based on the degree of exploration, the Classification stipulates seven resource categories, which makes a much greater number of categories, than those used by other countries and IAEA, thus causing certain difficulties in their comparison.

One should pay attention to the fact that out of the seven categories (A, B, C1, C2, P1, P2 and P3), A, B and C1 implies *explored resources*, C2 — as *preliminary assessment* and P1, P2 and P3 — prognosticated resources. Thus the classification in question is a system of hierarchy, essentially covering three main groups: explored resources, preliminary assessment and prognosis. Such three-member pattern is typical for many internationally adopted classifications.

Our classification is comparatively complex, because apart from resource inventory it also functions as a legal State document, specifying the mineral deposit readiness for production. The resource category as explored (A, B, C1) or preliminary assessment (C2) depends on the knowledge of certain parameters mainly the shape and attitudes of the orebodies, ore grades and three-dimensional picture, production and concentration technology (see Table I).

As the table shows, A, B and C1 categories, differ first of all in detail description of three-dimensional position of the orebodies in situ, i.e. their geometrical outline.

The technological parameters and economic values of all these categories are established with practically equal degree of variability enabling preparation of a production project plan.

TABLE I. CRITERIA FOR ESTIMATING A, B, C1 AND C2 RESOURCES

Estimation criteria	Requirement to criteria scope for various resources			
	A	B	C1	C2
Orebody shape and bedding	Completely clear	Clear in main features	Clear in general	Estimation after geological similarity
Ore and types grades	Calculated and delineated separately	Distribution regularities are established and statistically estimated	Statistical estimation	Sort grade are found present (absent)
Process and Mining modes	Completely clear	Clear enough to design production		Established by analogy
Outlines (contours) of resources in situ	Found by minings and walls	Found by minings and walls with some extrapolation	Found by minings and walls with geologically supported extrapolation	Found by extrapolation supported by few walls
	Resources as 100% prepared for production			Resources prepared for production in some part

C2 — resources are estimated on the basis of geological analogy, supported by a smaller amount of mining or drilling. However in some cases mine production projects include this category as well. Prognosticated resources are subdivided into categories following a different principle (see Fig. 1).

P1 — category covers the resources of orebodies still unknown, but prognosticated in known deposits.

P2 — category covers the resources of prognosticated deposits within determined ore districts and anticipated on the basis of anomalies and mineralization events.

P3 — category covers unknown deposits, prognosticated on the basis of general geological data.

The readiness of the deposits for production is determined according to the classification, and taking into account the complexity of deposits structure. This parameter (the complexity) is divided into four groups. There is a certain ratio between A, B, C1 and C2 categories established for each group: the ratio is obligatory if the deposit is to be accepted as prepared for production (see Table II).

As the table shows to admit the deposit for production its total resources depending on its structural complexity can be a sum of different categories: A+B+C1, B+C1, C1+C2. Due to such approach, C2 — resources in the deposits group III and IV ready for production are always better explored and estimated with higher reliability than the same categories for the deposits under preliminary exploration.

Most of the uranium deposits known on the territory of ex-Soviet republics, are in terms of structural complexity in group II and III. The principles of resources classification into category, can be illustrated with the following examples:

VEIN TYPE DEPOSITS

Only one of such deposits can be referred to as group II. This is Juzhnoe in Aldan ore district (Russia). The deposit consists of a huge vein system, whose total extension is more than 20 km. (see Fig. 2). The vein-shaped orebodies are located echelon-like in the zone of tectonically and metasomatically transformed rocks from 20 to 50 m thick. The orebodies 2–15 m thick, the extension from 0.3 to 0.7 km, up to one km and more. The uranium content ranges from 0.05 to 0.2 %.

For a limited extent the deposit was explored with several horizontal mining, at 200 m vertical distance. The orebodies were reached by drifts and sampling transverses (every 25 m). The space between horizontal tunnels was explored by fanlike boreholes drilled every 25–50 m.

The pilot block was covered with additional tunnels, uprise shafts and borehole grid of 12-25 m. The peripheral and deeper horizons were explored with borehole grid of 100 by 200, 100-200 by 400–600 m. The resources within the mining works contour are referred to as B, beyond the contour as C1 (with 100 by 200 m drilling grid) and C2 for the larger grid.

Most of the vein deposits come under group three. Such are all the deposits in Strelzovsky ore district, which is the mainstay of uranium resources of Russia. Figure 3 shows orebody N 1 of Strelzovskoe deposit, degree of exploration as on the moment of transfer for production (1968).

The orebody is about 700 m long, 2–10 m thick with uranium content varying between 0.1 up to several percent. The body was explored with several horizontal mines while the ore was reached with drifts and sampling transverses every 25–50 m. The total exploration grid for transversal works crossing the body in its longitudinal plane plus underground boreholes between the horizons is 25 by 25 or 25 by 50 m. The resources are graded as C1. As f or C2 category it is for the resources, covered

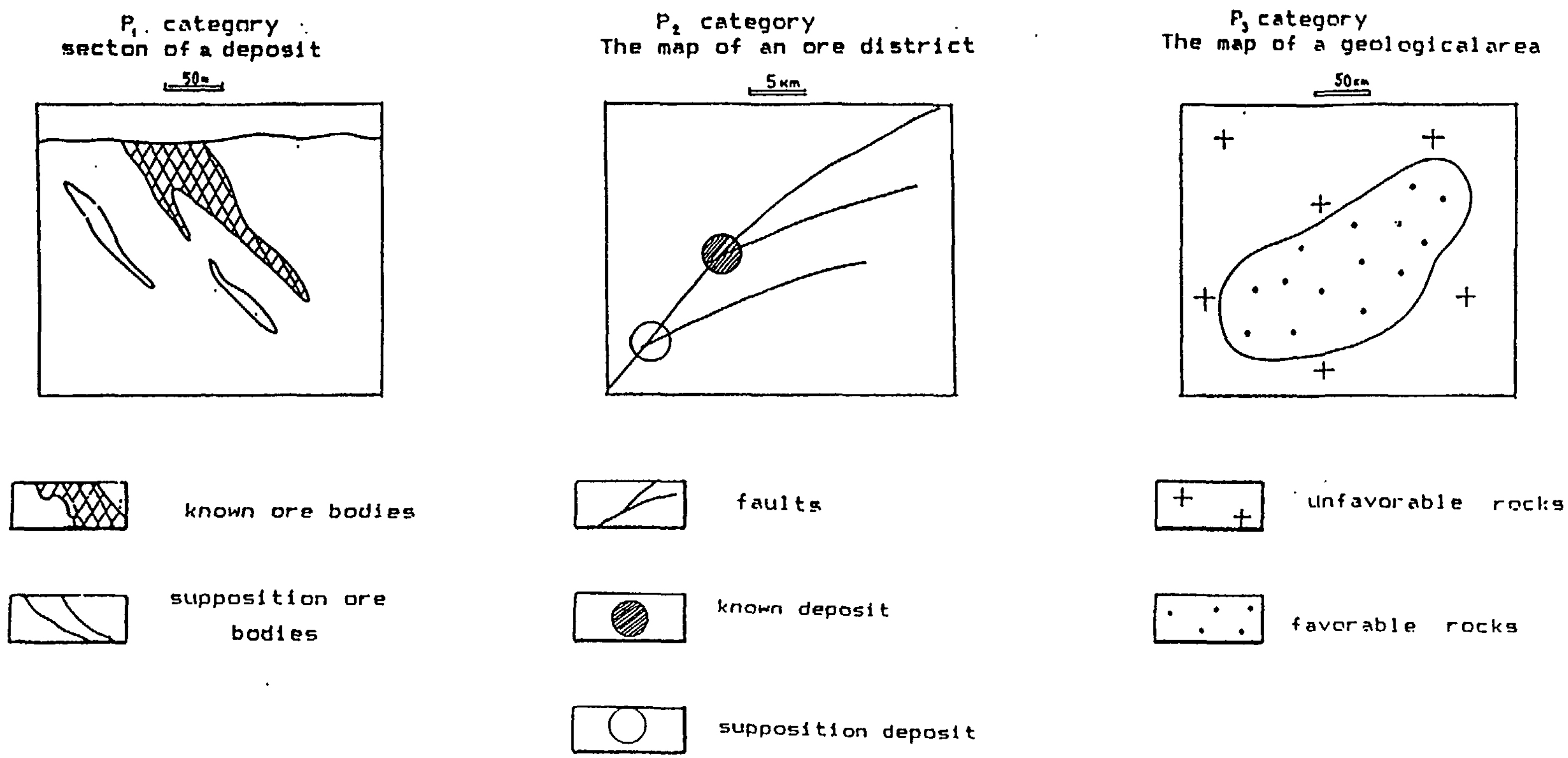

FIG. 1. The scheme for correlating prognostical resource categories by deposit form.

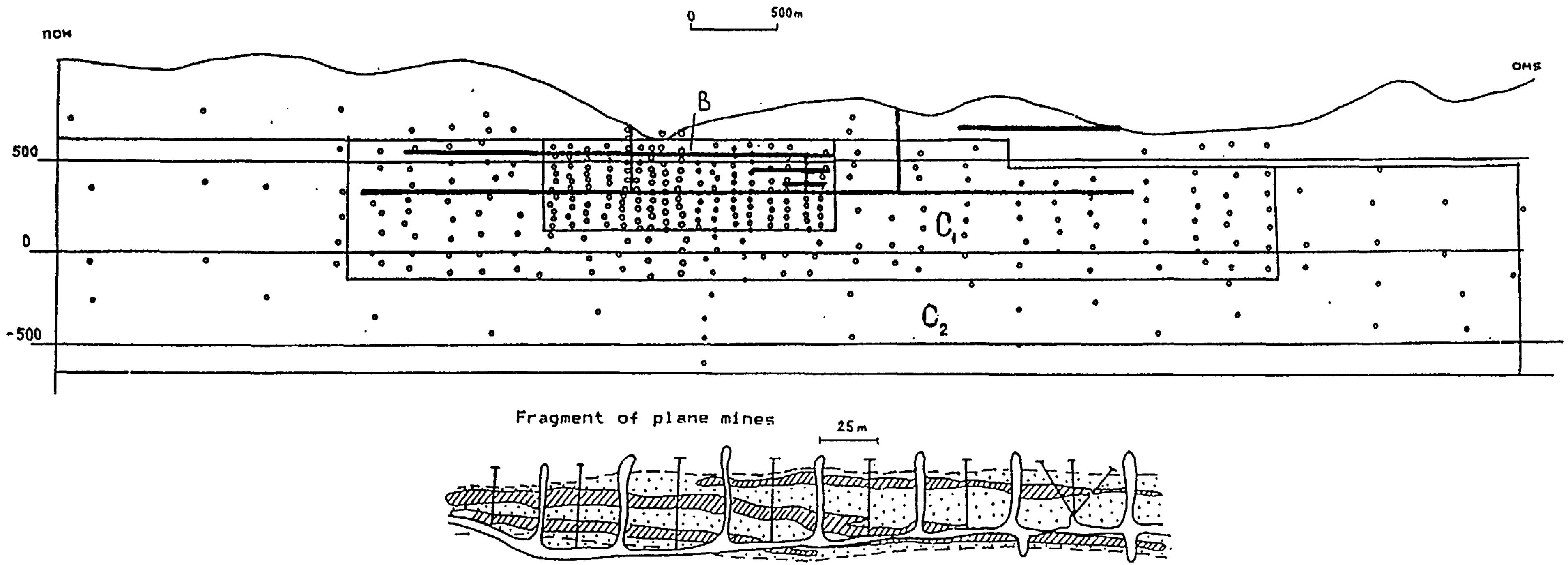

FIG. 2. Longitudinal projection of the Southern deposit (II group) (Alden district, Russia).

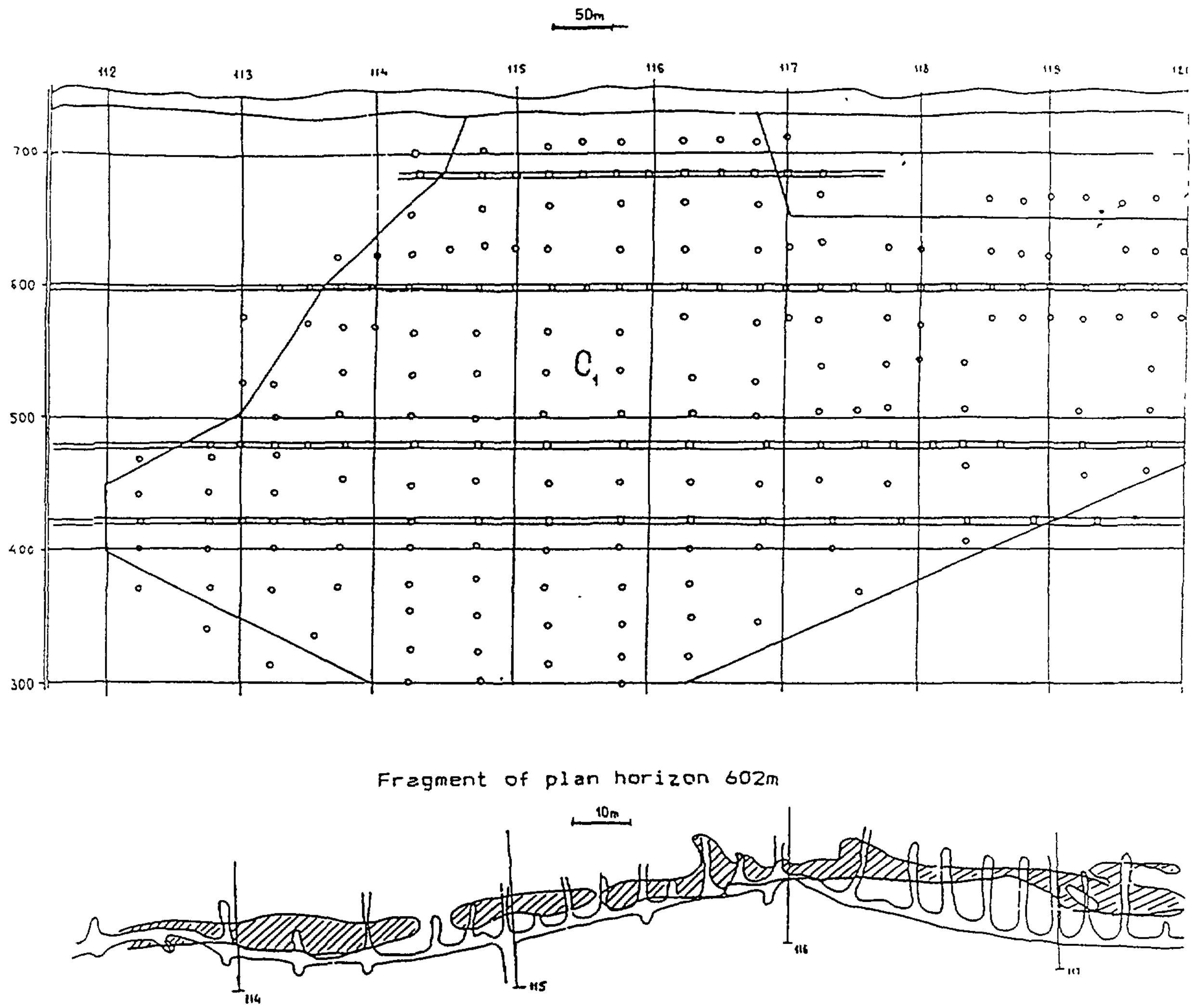

FIG. 3. Longitudinal projection of the Strelzovskoe deposit, Russia .

by borehole grid 50 by 50 and 50 by 100 m, mostly for those adjacent to C1 on the flanges and beneath.

As the above examples demonstrate, C1 — resources in Strelzovskoe deposit are explored as B on Juzhnoe deposit. And C2 in Strelzovskoe are covered with denser grid and estimated with higher reliability than in Juzhnoe. However in Strelzovskoe they make in total a comparatively smaller share of C1 resources.

At present there is no group IV deposits for commercial production of uranium in Russia and CIS republics. The Karamazar cluster of deposits now exhausted were the closest to this class. This group also includes well known vein deposits from Erzgebirge (Pshibram, Alberoda etc.), whose explored resources were estimated as C2 maximum. However, without this category no production at all of this deposits would have been possible.

ROLL-TYPE DEPOSITS IN SANDSTONES

These deposits in the Union countries are mostly produced by underground leaching, which prevents detailed study of their orebody geometry. Most of these deposits are large and refer to group II. Figure 4 shows a fragment of plan for Inkay deposits in Kazakhstan. Here they have prepared for production a number of orebodies on North-East flank of extended ore bearing strip (more than 100 km long).

FIG. 4. Plan map of part of Inkay deposit, Kazakhstan.

TABLE II. REQUIRED RESOURCES FOR CLASSIFICATION BY LEVEL OF PREPARATION FOR EXPLOITATION

Resources category	Necessary amount of resources of various categories (%) for deposit group			
	I group	II group	III group	IV group
A + B	30	20	-	-
A in that number	10	-	-	-
C1	70	80	80	50
C2	-	-	20	50

TABLE III. COMPARISON OF RED BOOK RESOURCE CATEGORIES WITH THE RUSSIAN/CIS CATEGORIES

	RAR	EAR-I	EAR-II	SR
The group of deposits	The deposits which are prepared for exploitation	The deposits which are preliminary explored	in total	
I - II	A + B + C1	C2	P1	P2
III - IV	C1 + C2	C3	P4	P2

In the explored area they show as B category covered by borehole grid 100 by 50 m with some reference profiles and experimental leaching spots. The bulk of the resources is shown as C1 covered with borehole grid 400 by 100–50 m. They show as C2 the resources on other flanks of the deposit covered with borehole grid 100–200 m in profiles every 400–800 m.

For smaller deposits of that type referred to as group III, they usually show as C2 the resources of narrow strips spotted by single boreholes in profiles.

For the comparison of the classification adopted by CIS countries and the classification used by IAEA for the "Red Book" we would suggest matching criteria as shown in Table III. The RAR category fits the sum of A, B and C1 resources in our countries. When it comes to deposits ready for production it seems correct to add into the amount some of C2 resources — as much as accepted in production project report.

EAR-I shall meet C2 resources in the deposits of group I and II, as well, as in group III and IV under preliminary exploration and graded as unprepared for production. EAR-II shall meet P1 resources for all deposits. SR corresponds to P2 resources. The resources, which in our classification go under P3 category, are not accounted by IAEA. In the statistics, presented for IAEA previously, we did not show this figures either.

By and large in spite of certain differences in approaches to resources classification we can find adequate comparative criteria. The system used by IAEA is convenient enough for all countries presenting information on the resources. Russia agrees to use this system, when supplying our data, the above considerations of comparison criteria to be taken into account.

COST CATEGORIES

The uranium resources in Russia, Kazakhstan, Uzbekistan and the Ukraine, before 1991 were split into three cost categories: below 80 rouble/kg, 80–120 rouble/kg, and above 120 rouble/kg.

These threshold values were derived from the followings: 120 rouble/kg corresponds to the top price of mineral uranium in concentrate, when nuclear power production still comes cheaper, than from thermal (coal) power plants. 80 rouble/kg corresponds to mean price for uranium in concentrate which the government used as a reference point in payments to the uranium concentration plants to cover the production costs, or even the least feasible plants, according to long-term output levels.

Any coincidence between the above mentioned cost limits in dollars as used in IAEA accounting system, is purely accidental.

Price instabilities as well as disintegration of the uniform economic area of the former USSR prevent us now from calculating new limit values for the adopted cost categories. At the same time we can feel reasonably confident that specific amounts of resources under any of this categories will undergo no substantial changes, even with considerable rise in the values of rouble for the adopted limit costs.

All uranium deposits registered in the State Balance get their feasibility assessment on the basis of special calculations estimating probable production costs for the projects under design. With the economic situation stabilizing and the rouble becoming convertible, Russia and other republics will in principle find no difficulties in applying IAEA cost categories when supplying their reports to this body.

The list of operations, whose costs are to be to included into comparison resources calculations for a specific deposit of any cost category are in principle the same operations, taken into account in feasibility studies in CIS countries.

It should be mentioned that for practically all functioning uranium production mines the cost level in modern prices and under existing dollar/rouble exchange rate is still much below $80/kg level, recommended by IAEA as the lowest cost category of the resources.

THE SYSTEM OF ACCOUNTING URANIUM RESOURCES

The new legislation in Russia stipulates the prospecting, exploration and production of uranium deposits as an exceptional right of the State. The uranium mineral resources are subject to government inventory on the basis of the present Classification of Resources.

The current changes of resources are reflected in the State Balance compiled by "Geologorazvedka" association (Geological Committee) and "Atomredmetzoloto" association (the Ministry for Nuclear Energy), of Russia. The current changes due to production and resources increments in situ are reflected in the Balance as of the first of January each year.

The uranium resources in newly discovered deposits, when transferred for production are checked by experts in the State Commission on Resources. Similar approach is still kept in other republics of the former USSR: Kazakhstan, the Ukraine and Uzbekistan. Until now, the resources of these republics and Russia were put under the same balance. However in the future the republics will apparently run their own balances.

With the application of uniform classification and long term practices in methods of resources estimation, this enable us to hope that the separate accounting of the Resources will not affect the reliability and variability of the resources figures as a whole. Unlike our western colleagues, we believe that mineral resources should be reported as in situ resources. Because production techniques vary, and accordingly the production losses.

XA9847833

IMPROVEMENTS TO THE QUALITY OF THE ESTIMATES OF US URANIUM RESERVES

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Abstract

Extensive work has been done in the United States in the estimation of uranium reserves. The government's role in uranium raw materials shifted from support of military programmes to assessing the supply available for commercial power generation. A comprehensive system evolved in which government staff estimated reserves for each property over a range of cost levels using standardized estimation methodology and criteria. The programme was assigned to the Energy Information Administration (EIA) of the Department of Energy in 1983 which has the responsibility for reporting on energy resources. As uranium supply had increased and demand had decreased, there was less concern about the adequacy of resources. In this situation, and with reduced staffing levels, the EIA adopted a two part interim approach to preparing reserve estimates. One used questionnaires to obtain uranium company estimates of their economic and subeconomic reserves, with company determined economic criteria. A second approach modified the earlier detailed government property estimates to account for production. The EIA developed a new system with the assistance of consultants and the uranium industry. The goal of the new system is to produce one set of estimates at various cost categories for each property based on a rigorous adherence to EIA criteria. Initial information is gathered from the industry through a revised annual questionnaire. Company estimates that conform to EIA standards are incorporated into the EIA reserve data base. Additional information is gathered for those estimates requiring clarification, primarily through detailed technical conferences with company staff. The EIA has the capability to prepare independent reserve estimates from basic drill hole data when required. Uranium reserves estimated for 1990 by the EIA include the initial results from the new methodology. The cooperation and support of the uranium industry have been excellent. Detailed evaluation of properties is continuing. Further work is being directed toward improving estimation techniques and analysing production levels obtainable from reserve levels at various cost categories.

INTRODUCTION

The United States has a long history of estimating uranium reserves. This information was of fundamental value in the planning of procurement programmes in the early days of defense nuclear programmes. Subsequently it was vital for the development of civilian nuclear power programmes. Reserve data are basic for understanding both the near and long term outlook for uranium supply and the potential economics of that supply. Such information can lead to development of adequate supplies and to employment of appropriate energy generation technology and production facilities. While there is much less concern currently about the adequacy of uranium supply, fundamental questions remain about the magnitude of uranium resources, and their costs of production and availability. Monitoring and study of uranium reserves and resources must continue if future shortages are to be avoided and sound planning by both the producers and the users is to be assured. To meet the changing needs of the users of reserve data, the Energy Information Administration (EIA) has developed a modified uranium reserve evaluation programme.

HISTORY

Initial work on estimation of uranium reserves in the United States was done in the 1940s as part of the Manhattan Project, the wartime effort to develop nuclear weapons. This activity largely concerned the uranium-vanadium deposits of the Colorado Plateau which contained most of the known deposits of uranium in the US at that time.

As the work of the Atomic Energy Commission (AEC), which succeeded the Manhattan Project, proceeded there were increasing needs to understand the extent and nature of uranium ore reserves. The demand for uranium was far in excess of known resources. Systematic reserve evaluations provided a gauge to assess the success of exploration and a basis for planning uranium procurement.

In 1952, a small ore reserves group was established at the Grand Junction (Colorado) Office. This group undertook the process of evaluating the reserves of all known deposits. The group established procedures and criteria for consistent evaluation of the resources, based on generally accepted engineering methods. At that time reserves were only a few thousand tons of uranium in many small deposits. Exploration activity was almost entirely done by the AEC. Drilling data and information gathered during the examination of privately owned deposits were the basis for the reserve estimates.

The AEC provided incentives for uranium exploration and production through guaranteed markets and prices, and through financial and technical assistance. These incentives, coupled with the discovery of larger deposits in other geologic environments, soon attracted many mining companies and individuals to the uranium business. As activity expanded the problem became one of estimating reserves from company developed basic data. The AEC was the sole buyer of uranium. A requirement to provide ore deposit basic data to the AEC was included in the procurement contracts. A close working relationship on monitoring and evaluation of reserves developed between the AEC and the Industry. This relationship was maintained over the years as the industry expanded and new companies entered the business.

Procedures for estimating reserves evolved that recognized the nature of uranium deposits and the geologic controls, the technology for mining and processing, and the costs of production. Reserves were estimated in various categories of reliability and at various costs of production. The categories of Indicated Reserves (which included Measured Reserves) and Inferred were used over the early years of the activity. The basis for economic evaluation initially was the AEC price schedule for uranium ores. Later, reserves were estimated at \$8.00 per pound of U_3O_8, and then at a range of cost levels. In the 1970s estimates were made at \$10, \$15, \$30, and \$50 per pound of U_3O_8 (\$27, \$40, \$80, and \$130 per kg U). These cost categories were modified as prices changed and to reflect inflation.

Techniques were developed that allowed processing of the increasing amounts of data being generated and employed a variety of estimation and evaluation methods. Computers, which were of the main frame type, and statistical techniques, were increasingly used. AEC engineers and geologists developed the software needed, as there were no commercial programmes available.

Some idea of the growth of the size of the effort involved can be gained by reviewing a few statistics. See Table I.

TABLE I. DRILLING, RESERVES AND PRODUCTION, 1950 AND 1978

	1950	1978
Meter Drilled	238 000	14.6 Million
Reserves, Tonnes	2 300	530 000
Number of Reserve Properties	< 100	1 500
Mine Shipments, Tonnes U	600	15 500

In 1950, about 238 000 metres of surface drilling for uranium exploration and development were completed. Reserves were about 2301 tonnes of uranium contained in less than 100 properties. Mine shipments of ore contained about 600 tonnes of uranium. In 1978, during the height of uranium activity, some 14.6 million meters in 104 400 holes were drilled. Most of these data were collected by the AEC and converted to digital form and processed in the reserve programme. Reserves producible at the $80 per kg U cost level had increased to 530 000 tonnes uranium. These reserves were in 1500 properties in 15 different States. Some 15 500 tonnes of uranium in ore were shipped from 391 different sources.

The emphasis of the earlier programmes was placed on the estimation of ore reserves. As it became apparent that projected needs were much greater than available reserves, there was an increasing interest in understanding the possible extent of resources beyond those meeting the restrictive criteria of reserves. Consequently the resource programme developed into a fully integrated evaluation of uranium resources of all categories of reliability and economics. The concern was about the potential supply and economics of uranium for the long term, some 30 or more years ahead and producible at costs well above prevailing prices. This information was needed to support decision making relative to deployment or the light water reactors and for programmes to develop improved reactor types such as the breeder reactor.

A skilled work force in reserve and resource appraisal was developed in the AEC and extensive files of data on all US uranium deposits was assembled. Efforts were expanded to study the nature and extent of uranium resources, world wide, This work included cooperative efforts with the Nuclear Energy Agency and the International Atomic Energy Agency.

ESTIMATION PROCEDURES TO 1983

A consistent approach to national uranium ore reserve estimation was employed by the AEC and its successor agencies, the Energy Research and Development Administration (ERDA) and the Department of Energy (DOE), through 1982. In this procedure, government staff engineers and geologists, prepared reserve estimates for each deposit using basic sample and cost data from the mining companies. Data were gathered in field offices established at different locations around the country. During the 1960s, the field office staff made the initial reserve estimates using procedures and criteria set out in an ore reserves manual. Reserve estimates were reviewed in Grand Junction and, upon acceptance, included in the national reserve data base. In addition to the study of resources, evaluations and projections of the production capability that the resources could support, and as planned by the industry, were also made. With the increasing reliance on computers in the late 1960s, deposit evaluation became more centered in the Grand Junction office.

A key aspect of the programme was the close contact with the mining and exploration companies, through the field offices and through frequent visits and conferences with the Grand Junction staff. The data, estimation criteria, procedures, and results were reviewed annually in meetings with the mining companies key staff. This assured the completeness and accuracy of the results. Annual presentations of the findings of the various studies, were provided to the public through annual conferences at Grand Junction and by the issuance of a variety of reports.

In the early 1980s, there was a diminishing concern about adequacy of uranium supply. Growth in nuclear energy and uranium demand, and future productions of need were greatly reduced. Uranium supplies seemed adequate for an extended period. The US uranium industry was undergoing a severe retrenchment. Exploration and development had decreased sharply; from the 104 400 holes and 14.6 million meters drilled in 1978 to only 9970 holes and 1.6 million meters in 1982 (Table II).

In addition to the changing uranium outlook, there were pressures to reduce government staffing levels. As a result, a major change in the uranium programme occurred in 1983. The uranium resource programme was transferred from the Nuclear Energy programme of DOE to the EIA. This component of the DOE has the basic assignment of gathering and reporting national energy related data including coal, and oil and gas. With the transfer of the activity, reserve programme staff levels were greatly reduced and the activity moved from Grand Junction, Colorado to Washington D.C. The extensive files and data base on the uranium industry were also moved to Washington.

TABLE II. EXPLORATION AND DEVELOPMENT DRILLING, 1978 AND 1982

	1978	1982
Number of Holes Drilled	104 400	9 970
Meters Drilled	14 630 000	1 646 000

EIA ESTIMATION PROCEDURES 1984 TO 1989

The procedure adopted by the EIA for reserve estimation was considered to be an interim approach pending development of a permanent system. The modified approach was also influenced by the limited staff available and a changing view of information needs. It was judged that less detail on reserves was needed, and more information on other topics that were indicative of the viability of the domestic uranium industry was required. The new approach had two components . The first component was to employ questionnaire to gather industry estimates of their economic and subeconomic reserves. The second was to revise the previous DOE property by property estimates at various cost categories, primarily to account for production.

A questionnaire was sent annually that requested company estimates of their reserves. The companies were to use their own criteria as to what was economic or subeconomic, considering their sales contracts and their assessment of the uranium market. In addition, data on criteria and costs used in estimating reserves, and a variety of exploration, property, production and sales data were also requested. The reserve estimates provided by the mining companies were totaled and reported by the EIA as national economic and subeconomic reserves.

For the second component of this procedure, the EIA continued to report reserves in various cost categories derived from the property by property reserve estimates previously made in Grand Junction. These revised estimates were made primarily by subtracting production from the estimates and by proportionately reducing reserves at other cost levels. No modifications were made to reflect changes in mining methods or additional exploration results, either from surface drilling or mine development. As exploration, production and mine development were at low levels, such adjustments provided reasonable estimates of reserves. As time progressed, however, the cumulative effects of such procedures became less reliable.

PROBLEMS IN METHODOLOGY

Questions arose concerning the reliability of reserves reported by the companies. The economic criteria used by the companies varied widely, as the price levels received in existing contracts ranged from less than $20 per kg U to well over $100 per kg U. In addition there were differing interpretations of the prices that might be attainable in the market in the near and longer term future. In addition, there are many variations in estimation methods and criteria, and in company policy, concerning reserve estimations. Aggregate estimates of the reserves reported by companies provided little insight into the availability of uranium at various cost or price levels or to the reliability of the estimates. During this period, the EIA staff had limited direct contact with the industry and little opportunity to exchange views on reserve data. It became clear that the estimates were becoming of questionable reliability and that the estimates were not being used by the industry as they had prior to 1984.

The revisions to deposit estimates by subtraction of production from a previous reserve estimate could only be expected to be reliable for a few years for active deposits. Modifications to the estimates to reflect new knowledge on the character and ore distribution in the deposit must be made from time to time to reflect the current situation. Mining invariably will show that an ore deposit is different from the interpretation at the time of the previous estimate. Some ore will be disproved, other ore may be added. The mining experience may show differing costs and recoverability. Low prices may cause changes in mining methods from that previously practiced or planned. Inflation would change costs. Mining of low cost resources during periods of low price might lead to loss of parts of the deposit or make remaining reserves available only at much higher costs. Surface or underground exploration and development drilling may add considerably to partially delineated deposits. Technological advances, as in the case of in-situ leaching, can change costs and the approach to production for some types of deposits. The accumulation of these factors tended to make the adjusted reserve estimates less certain and of less use in reserve and supply analysis.

In view of these problems there was increasing dissatisfaction with the reserve estimation procedures. A new approach was necessary.

A NEW APPROACH

During 1987 and 1984, the EIA reviewed the problem with assistance of consultants and the industry. This review led to the development of a new approach to estimation of national uranium reserves. The basic new strategy seeks to develop a more consistent and reliable appraisal of US uranium reserves. This is done by maximizing the use of company information and employing techniques that can lead to a variety of reserve estimates with a minimum of industry and EIA staff effort. Basic to the programme is a closer working relationship with the industry. This leads to a better understanding of the procedures of reserve estimation followed by the uranium companies. In addition, the goals and criteria of the EIA for uranium reserve estimation are more fully defined, with the objective of getting industry support to reach the goals.

Emphasis in the new approach is on the major uranium properties, and on properties with changes in mining methods. The value of this approach can be seen in Figure 1. This shows the distribution of US$80 per kg uranium reserves for the 100 largest reserve properties. The 100 largest deposits contained 98% of the reserves. The 30 largest properties contained 76% of the reserves. By concentrating work on these properties the overall reserves picture can be more quickly reassessed. Similarly, concentrating on the 50 largest reserve controlling companies would cover about 86% of US reserves. The basic components of the new programme can be summarized as follows;

- Use of a revised annual questionnaire for gathering company reserve and collateral data. A simplified questionnaire focuses on the fundamental information desired. EIA reserve needs and estimation criteria are clearly set out. Reserve data are requested for the EIA cost categories, if available, or for the cost levels adopted by the company. Flexible company responses are encouraged, in recognition of the varying problems and approaches in the industry.

- Analysis of the information provided in the questionnaires and of the companies' procedures and criteria for reserve estimation through on site technical reviews with company staff.

- Where company estimates are found to meet EIA criteria, acceptance of the company estimates, and inclusion into the EIA national reserve data base.

- Where company criteria do not conform to EIA criteria and where possible, modification of company estimates to meet the EIA criteria.

- Where adjustment of company reserve estimates is not possible to conform to EIA criteria and needs, development of independent EIA estimates of deposit reserves using basic data provided by the companies.

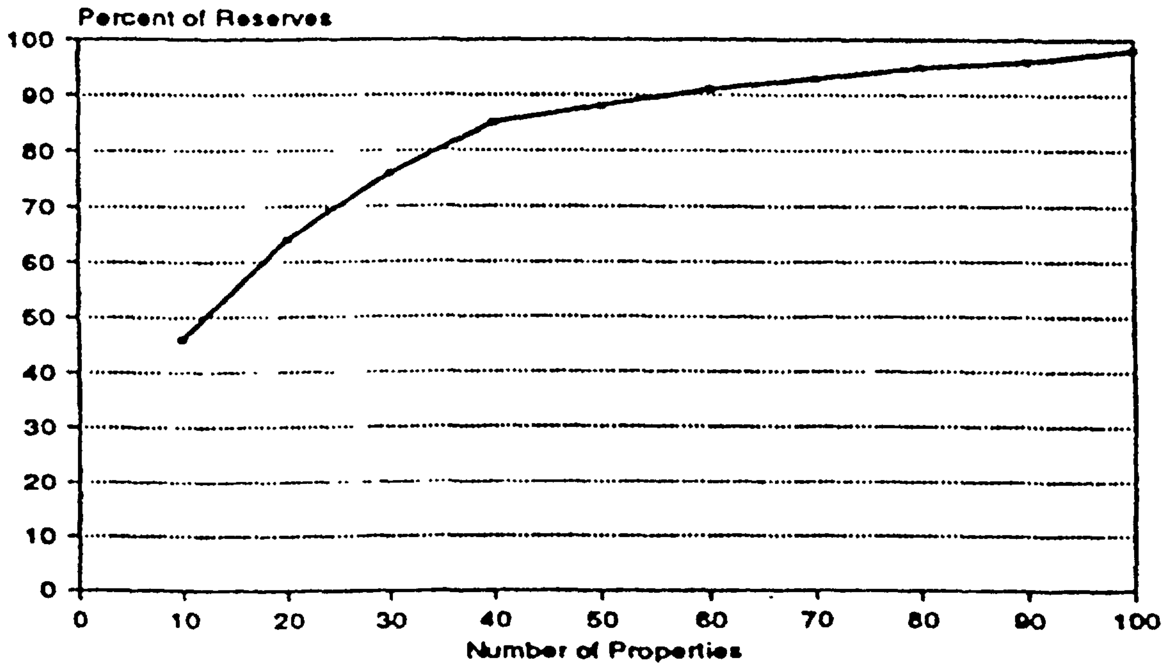

FIG. 1. Reserve distribution properties ($80/kg U).

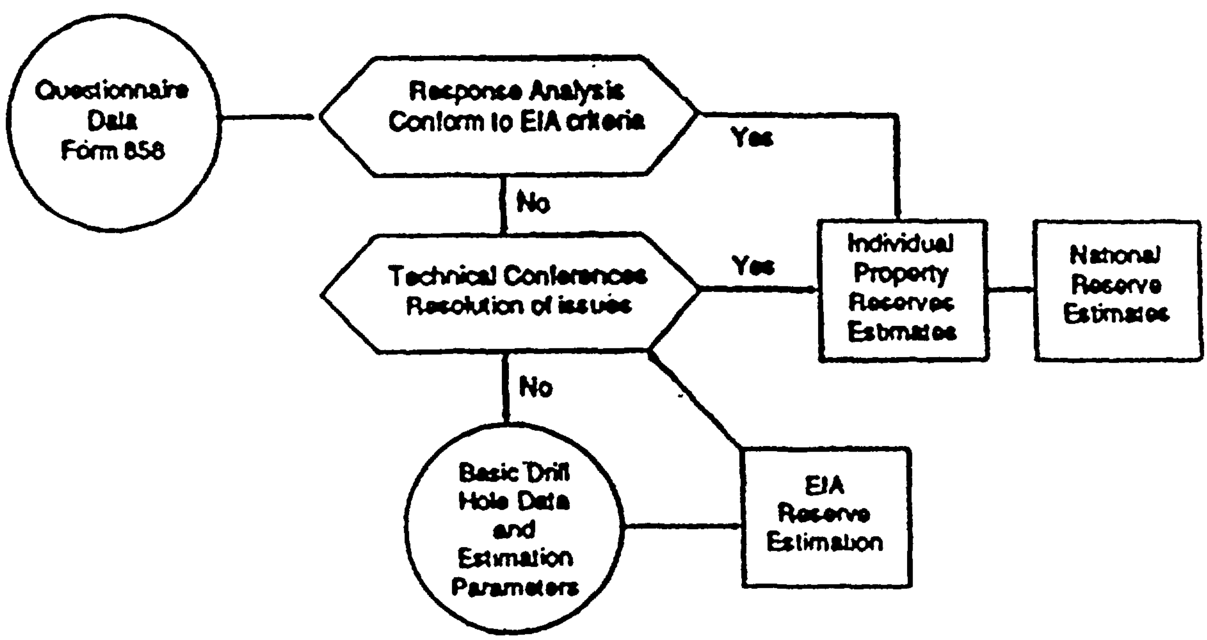

FIG. 2. Major programme component relationships.

- Development of improved basic information needed for reserve estimation, such as cost data, and improvement in reserve estimation techniques.

- Compilation of the various accepted estimates into a national reserve appraisal and reporting of the results annually.

The interrelationships of the major programme components are shown in Figure 2, from questionnaire to compilation of national reserve estimates. Each major component of the programme is discussed in more detail below.

QUESTIONNAIRE

The primary approach of the EIA in gathering energy information is by annual questionnaires sent to the industry. In the uranium area, the questionnaire is Form EIA-858, "Uranium Industry Annual Survey." The current version of the form dealing with uranium reserves has been considerably shortened and simplified. The revision should particularly ease reporting for non-conventional production, such as in situ leach and by-product operations. The goal was to focus on the essential information needed under the new strategy, to ease the burden on respondents, and to allow more flexibility in the information provided. This will lead to more thorough and useful information from the companies, and provide the basis for a closer working relationship with the industry. The final questionnaire reflects industry comments and suggestions from review and discussion of draft versions.

As in previous practice, all information is closely held within the EIA and treated as "Company Confidential". The importance of confidentiality is well understood and special care is taken to assure that the data is protected.

Form 858 contains a general instruction section and two main parts seeking data. Schedule A covers uranium raw materials activities and Schedule B covers uranium marketing activities such as sales, imports, prices, inventories, and supply commitments.

The improved survey gives the respondent the option to use a microcomputer version of the form. This should ease filling out the form for the companies and in using the data by the EIA. The forms provided to the companies are preprinted with previous data for each property under control of the company. This allows the respondent to mark in corrections, thereby reducing the need to fill in repetitive information. Data can be transmitted to EIA by paper copies transmitted by mail, through facsimile machines or by computer diskette.

Schedule A is subdivided into four parts. Part I covers exploration and development activity, Part II covers reserves and mine production, Part III covers milling and processing and Part IV covers employment. There are 17 sections or "items" of information requested in Schedule A. There is a section that provides an opportunity for comments on any aspect of the information presented in Section A. A glossary provides the respondents with the EIA definitions of key terms.

Schedule A, Part II, (items 7 through 12 of the questionnaire) is the portion of interest in this paper. This section has been extensively rearranged and simplified as part of the new EIA approach to reserve estimation. Data is collected for each property on the topics listed in Table III. The series of questions requests company estimates for individual properties and information on the criteria and methods used in making the estimates, as follows.

TABLE III. SECTIONS OF REVISED FORM 858, SCHEDULE A, PART II; RESERVES AND MINE PRODUCTION

Item 7	Property Information Identification Ownership Control Status of Development
Item 8	Property Reserve Estimates
Item 9	Operating Costs
Item 10	Capital Costs
Item 11	Reserve Estimation Parameters
Item 12	Mine Production

Item 7, Property Identification and Ownership, requests the names and location of the property and the current ownership and control. Status requests the current stage of development and activity at the property, that is, in exploration, development or production stages, and the types of reserve and feasibility studies completed.

Item 8, Reserves, requests company reserve estimates for the property, reported separately for open pit, underground, in-situ leach, and other types of operations. Reserves are requested by forward cost categories of \$15, \$30, \$50, and \$100 per pound of U_3O_8, (\$40, \$80, \$130, and \$260 per kg U) to the extent available, or for cost categories used by the company.

Item 9 requests the operating costs per ton of ore used in the reserve estimates presented. Cost per pound is obtained for in-situ leach operations. Cost elements include mining, haulage, royalty, milling, and indirect operating costs.

Item 10 requests capital costs for mine development, and mill and plant construction.

Item 11 requests information on he parameters used in the reserve estimation, such as cutoff grades and thickness, tonnage factors, area of influence and recovery factors. Descriptive data, such as number of holes involved, average grade, thickness, and depth, are also obtained.

Item 12 requests data on mine production from the property for the year in ore and in contained uranium. Data on vanadium production are also requested for those properties with vanadium values.

The initial mailing of the new version of the form was made in December 1990 seeking data on 1990 activities and year end reserve and property status. Schedule A of form 858 was mailed to 104 companies. Responses have been received and reviewed.

TECHNICAL REVIEW

The industry responses to Form 858 are reviewed in detail to decide if estimates provided can be accepted without modification or what additional steps should be taken. A fully completed form may provide an adequate basis for such a determination. The review is supported by other information available to the EIA on the deposit in question, and knowledge of the company reserve estimation practice. Sometimes, it is necessary to obtain additional details by telephone or by written request. For the early years of the programme, particularly for major uranium companies and deposits, an in-depth technical review with company staff will be needed. The incorporation into the EIA data base of some of the property reserve estimates provided by the companies will thus be deferred until technical meetings have been held.

The technical reviews with the companies seek to establish thorough understanding of the company practice and procedures in reserve estimation. The meetings will also establish a better understanding of the company policies and problems, and very importantly, build a better working relationship with the company. The goal is to enlist the company's assistance in developing sound national uranium reserve estimates.

The initial meetings seek to involve high level company officials to explain the EIA programme and goals and to assure corporate support. Subsequent meetings are with technical Staff involved in reserve estimation. Such meetings are usually at active field sites and may include mine and plant visits. Proposed agendas for the meeting are provided to the company in advance to assure understanding of the scope of the meeting. This also assures that the proper staff are present and that they are prepared for the meeting. Typical meeting agendas cover the topics shown in Table IV.

A more detailed check list has been developed for EIA staff on each topic to assure that all pertinent matters are covered in the meeting. The meetings are informal and encourage company comments and suggestions.

During 1990, meetings were held with 12 key companies involving over 100 properties. The properties were estimated to contain about 60% of the $80 per kg reserves for the US, as of January 1, 1984. During the conferences, reviews were made of properties already in the EIA records and new properties were added. About 50% of the properties examined during the company conferences have been reevaluated since January l, 1991.

TABLE IV. COMPANY TECHNICAL CONFERENCE AGENDA

EIA Role in National Energy Resource Information
EIA Uranium Programme Plans and Strategy
Company Reserve Estimation Procedures, Methodology and Criteria
Company Reserve Estimates, by Property
In-Depth Review of Selected Properties
Company Capital and Operating Costs
Way for EIA to Handle Company Reserve Estimates
Company Production and Exploration Activities and Future Plans
Future Actions by EIA and the Company

The response and cooperation of the companies have been excellent. They have strongly supported the new EIA approach to national reserve estimation. Their positive response provides assurance that the programme will be successful. The input to the programme from the companies has been very helpful and has led to increased industry participation in the national uranium reserve programme.

MODIFICATION OF COMPANY ESTIMATES

Review of company responses to Form 858 and information from the technical reviews may indicate the need for EIA to modify company estimates so they conform to EIA criteria. The most common problem expected is that company estimates do not conform to the cost criteria selected by the EIA Knowledge of company procedures and of the nature of the reserves in the ore deposits in question can provide a suitable technical basis for modification of estimates or development of additional estimates with alternative criteria. Parametric relationships for deposits amenable to extraction by different types of methods, such as where in-situ leaching can be used in place of conventional mining, are being studied to help in this activity. The goal is to find means to get to an acceptable estimate without doing a complete estimate of the reserves. This would require much more time and manpower.

INDEPENDENT EIA RESERVE ESTIMATES

If no suitable means to modify company estimates can be developed it will be necessary for the EIA to prepare independent estimates. These independent estimates also can provide the information needed to develop the means for modifying future company estimates. Thus it may not be necessary to continue to do the independent EIA estimates once deposit and procedure relationships are developed and well understood.

The EIA will make independent reserve estimates using company supplied data and data in EIA files on the deposit. As many companies are using computer methods for handling sample data and for reserve estimation, acquisition of data should be simplified from earlier times when the basic analog hole log records on paper were usually obtained. Such logs require considerable effort in digitizing and entering into the computer records. Some logging records now include digital magnetic data as a routine part of the logging procedures.

The basic computer programs now in use were derived from the programs developed in Grand Junction for the uranium ore reserve programme. These programs have been modified to run on IBM compatible "PC" computers, which now have the capability of doing computing jobs only possible previously on main frame computers. The modification of the programmes was supported by the IAEA and published in 1988 as TECDOC-484, entitled "User's Guide for the Uranium Ore Reserve Calculation System URAD". The EIA has made some additional modifications to ease use of the system, to allow use of a variety of basic data formats and to allow plotting of data used in the system. These modifications will ease the estimation of reserves from company data.

The validity of the basic computer techniques and programs was well established through their extensive use in the Grand Junction program. Many changes, however, have been made to allow their use on PC's and to accommodate additional data formats. Test cases have been run to verify the reliability of the modified software. As part of this review, cooperative studies with industry have been carried out, comparing results from the use of different estimation procedures and computer programmes and different estimation criteria. These studies have provided confidence in the programs and techniques now in use.

As the EIA programme will be dealing with different types of ore deposits to be mined in varying ways and with data formatted and processed by the mining companies, it is important that the system used by EIA have considerable flexibility in data handling. To aid in developing that flexibility, additional software, including commercial programmes in use by the mining companies, is being investigated. Improvement and modification of software will be a continuing activity.

IMPROVED RESERVE ESTIMATION DATA AND TECHNIQUES

To assure well founded evaluation of company provided information and to support independent EIA estimates, efforts continue to improve a variety of basic and ancillary data needed for reserve estimation. These data relate to an understanding of the nature of the deposits, which influences areas of influence; mining and processing technology, which effects costs, recoveries, and mining thicknesses; and to industry production practice and costing.

Our goal is to have reserve estimation methods that produce estimates meeting EIA criteria for a variety of parameters and that require a minimum of labor and time. They also should have the flexibility to handle different types of data from geologically variable deposits, which are to be mined in various ways. These data and technique developments will be pursued in parallel with the estimation programme and will investigate different approaches.

ESTIMATE COMPILATION AND REPORTING

As estimates are accepted as conforming to the EIA standards, the data are entered into the national uranium reserve data base, This allows for flexibility needed for the EIA s analytical and data reporting requirements. The data are used to asses the current status of the US uranium industry, as well as to form the basis of estimating future supply capability.

The *Uranium Industry Annual* report, published by the EIA, contains a variety of information on the US uranium industry, including updated resource estimates. In addition, information will be presented in the publications of the OECD Nuclear Energy Agency and the International Atomic Energy Agency and in papers presented at industry meetings, such as the annual Uranium Seminars of the US Council for Energy Awareness. All data will continue to be reported in an aggregated form so as not to divulge information on any one company.

RESULTS OF THE NEW APPROACH

The results of applying the new approach to estimating reserves for 1990 are summarized in Table V. As the new approach has not covered all the properties and companies involved, these estimates only partially reflect the new findings. At the end of 1990, the reserve estimate for the $80 per kg U forward-cost category was 101,900 tonnes uranium held in 227 properties. The $130 per kg U reserve estimate was 356,000 tonnes uranium held in 568 properties.

The net decrease in reserve estimates for 1990 compared to 1989 was established by the EIA staff largely through the reevaluation of known properties (Table V). The reevaluation process included (1) the modification of company data to meet EIA criteria and (2) the results of the EIA conducting independent reserve estimates from basic drill hole data received from companies at technical meetings.. "New" reserves, or those reserve estimates for properties that were added to the EIA data base as a result of findings made at company meetings, contributed to 7% of the total, estimated reserves for the end of 1990.

TABLE V. CHANGES IN $80, $130, $260 PER KG U FORWARD-COST RESERVE ESTIMATES DURING 1990 (TONNES URANIUM)

Item	$80/kg U	$130/kg U	$260/kg U
Reserve, end of 1989	106,500	369,000	591,000
New Reserves	7,300	8,800	10,400
Reevaluation[a]	(9,600)	(19,200)	(15,800)
Depletion			
(Production and Erosion)	(2,300)	(3,500)	(4,600)
Reserves, end of 1990[b]	101,900	356,000	581,000

[a] Net additions and subtractions.
[b] Does not include reserves from byproduct facilities.

Based on the evaluation of company data, the EIA assessed the distribution of reserves most likely to be extracted by various types of mining methods. Conventional underground mining continues to be the most dominant class, comprising over 50% in each cost category. The share of reserve estimated to be amenable to recovery by in-situ leaching at the end of 1990, however, has increased compared to 1989 by 32, 18, and 16 percentages, respectively, for the $80, $130, and $100 per kg U forward-cost categories.

PLANS

Work is continuing on all aspects of the new approach. The goal is to develop sound and accurate national estimates of uranium reserves at a variety of cost levels, that are well understood, and arrived at with a uniform set of standards. Working closely with industry, improvements in data gathering and analysis will be sought to produce acceptable estimates with a minimum of effort by industry, and by the EIA. Meetings will continue to be held with industry staff to complete our technical reviews of the principal companies and deposits involved.

Improvements in analytical and reserve estimation procedures will be pursued, including improvement in current software and acquisition of additional programmes. The EIA seeks cooperative activities with the industry and internationally to improve reserve estimation technology. Development of better understanding of the parametric relationships of ore reserves, including costs, will continue. Analysis of the production levels attainable from reserves at various cost levels will be undertaken.

CONCLUSION

The new approach to developing national uranium reserve estimates adopted by the EIA is expected to provide a reliable set of data that will have the confidence of the industry. The method will draw on company data to the greatest extent possible. Company estimates will be used where possible, or they will be modified to EIA criteria. As necessary, independent estimates will be made by the EIA using company data. Priority is given to the larger deposits and the companies with the largest reserve holdings. This will provide the fastest improvement to the reserve estimates.

A close working arrangement with the industry is fundamental to the programme. The revised programme of data acquisition and technical review is now well underway. Industry acceptance has been very good. A closer working relationship has been established that will benefit the uranium industry and those who rely on EIA data on uranium.

PRINCIPLES OF ECONOMIC EVALUATION OF URANIUM RESOURCES IN CANADA

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Abstract

The uranium resources of Canada occur in deposits associated with unconformities in Proterozoic basins and adjacent areas. Classification of the resources is based on the confidence in the estimates and on their economic viability. The system is fully compatible with IAEA/NEA classified systems. The methods of estimating and classifying the Canadian resources is described.

PRESENT STATUS OF URANIUM RESOURCES

Uranium resources of all technical and economic categories occur in deposits associated with unconformities in Proterozoic basins and adjacent areas. The resources associated with other types of deposits either have been depleted or are under present market conditions uneconomic.

The largest amounts of the economic resources have been identified in the Saskatchewan part of the Athabasca Basin. Individual deposits there contain large quantities of high grade resources (e.g. the McArthur River (P2 North) deposit contains 160 000 tonnes U in ores grading 12.7% U, the Cigar Lake deposit contains 150 000 tonnes U in ores grading 7.8% U).

The remaining economic resources have been identified in the Northwest Territories in deposits which occur in rocks associated with the Thelon Basin.

If and when it is required due to actual or long range economic (market) conditions, the quantities of resources are revised (e.g. due to termination of contracts for deliveries of uranium concentrates from the Elliot Lake quartz-pebble conglomerate deposits, their resources have been reclassified as uneconomic).

TECHNICAL-ECONOMIC ASPECTS OF RESOURCE EVALUATION

Classification of the resources is based on the confidence in their estimates and on their economic viability. The classification system is fully compatible with the IAEA/NEA classification scheme as documented in the "Red Book".

In respect to confidence in the estimates, the classification takes into account the calculated (geostatistical et al.) or empirical (per analogiam) parameters, which determine the requirements for type, density and technical conditions of sampling.

The classification according to the economic viability is based upon establishing economic cut-off grades.

QUANTITATIVE ASSESSMENT

The resources are reported as quantities of metal recoverable from ores (i.e. after taking into account (subtracting) losses of metal during the mining and milling processes.

Exploitation method (mining, in situ leaching (ISL) etc.) has to be clearly defined and must accompany the estimated quantities.

However, in order to facilitate optimization of the operations and eventual revisions of the resources due to changing technical-economic conditions, the data base should contain estimates of resources "in situ" as well as quantities of resources at "multiple" cut-of grades.

CONCEPT OF CLASSIFICATION INTO COST CATEGORIES

The first phase of the classification is based on *break-even* principle, which correspond with the lowest possible cut-off grade. The input for this phase includes all the estimated basic costs: (a) operation, (b) capital investment, (c) taxes, royalties and legal, (d) additional R&D and exploration, (e) environmental impact, (f) decommissioning, (g) contingency.

The economic categorization takes into account additional factors, such as interest on borrowed money, expected profit etc.

The calculations are conducted according to the formula:

$$COG = (I+MD) \times (C/P+ML) - (DG) \times (MD), \text{ where:}$$

COG	=	cut-off grade in kg U/tonne of ore
MD	=	mining dilution (in decimal)
C	=	total costs in $/tonne
P	=	price in $/kg U
ML	=	mining losses in kg U/tonne, and
DL	=	dilutant grade.

During the life of the property, the cut-off grades may change in order to reflect financial status of the operation at any point in time. Capital and production costs are the most influential variables that affect the cut-off grades and economic structure of the resources. Because of dynamic nature of the uranium market, optimization studies during the mine operations are inevitable.

For that reason computer-assisted economic models employing multiple cut-off grades scenarios are useful tools for global assessment of the viability of the resources during the life of the property. An important part of these models are the grade/tonnage curves.

FEASIBILITY STUDIES

The most important document for the decision to start the exploitation of a deposit is a feasibility study. It represents an audit of ore reserve estimates, engineering and cost-related parameters. It should include a risk analysis, where probability distributions are shown for each key parameter. It must be a basis for optimal use of mineral resources under optimal economic conditions.

A feasibility study may change final classification or size of mineral resources. For example an appraisal of uranium resources of the Cigar Lake deposit before completion of the feasibility study was 110 000 tonnes of uranium metal in ores grading 12.2% U. The final feasibility study demonstrated that the deposit can yield 150 000 tonnes of uranium from ores grading 7.8% U.

CLASSIFICATION SYSTEM OF THE MINERAL RESERVES AND RESOURCES OF UKRAINE

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Abstract

This paper describes the system used to classify the resources and reserves of all minerals and fuels in Ukraine. The classification system is part of an official procedure determined by the Ukrainian State Commission on Reserves. Following preparation of resource estimates the results are registered with the State, which maintains an official inventory of all mineral resources. This paper compares the Ukrainian system to, and finds it compatible with the United Nations International Framework of resource classification. The UN system is based on economics of production and mineability.

1. GENERAL CLAUSES

1.1. The classification defines the common principles of the calculation and state registration of the reserves and the estimation of mineral resources for the State Fund of Ukraine.

1.2. The prospected and preliminary estimates reserve of resources and also the perspective resources of oil and gas are calculated and registered in the State balance of the Ukrainian mineral resources based on the results of geological exploration works (GEW). This includes all of test mining and drilling carried out during the process of commercial development of mineral deposits. The balanced and, conditionally balanced reserves and resources of solid, liquid and gas-like mineral resources are subjected, to state registration. These estimates underwent the examination and estimation of the Ukrainian State Commission on the reserves of mineral resources (SCR), and also the additional reserves discovered during deposit development. New deposits (fields) are added to the State balance according to the decisions of the State Commission of Reserves (SCR).

1.3. The perspective and prognostic estimated mineral resources are quantitatively estimated for the limits of all prospective areas based on the results of geological, geophysical, geochemical and other evaluation methods.

1.4. The reserves are calculated and registered, the resources are estimated separately for type of mineral resources and the direction of their commercial usage.

1.5. The reserves of the complex fields of the main and jointly bedded mineral resources and also the present useful components must undergo estimation and registration. The necessity of their commercial usage is established by the standards on mineral raw materials. The reserves of associated mineral resources and components are calculated and registered according to the "Demands of complex studying of the mineral resource deposits which are sent to the State examination estimation".

1.6. Quantitative estimation of prospective and prognostic resources is complex. For this aim the demands as to the quantity and quality of mineral resources and also the presence of useful components in them have been used. Is also necessary to take into consideration the standards of the known analogical deposits together with the possible changes of these demands in the nearest future.

1.7. Estimation and registration of the mineral reserves and the available useful commercial components are made in the case of their presence in the earth. Recoverable reserves of mineral resources are established according to the optimal system of development, which is substantiated by variational technical-economical calculations. These reserves include the losses during extraction, enrichment and processing of raw materials. The reserves of the associated useful components, which are accumulated during the processing of mineral raw materials in goods concentrates, products of metallurgical or another redistribution are calculated and registered so by the presence in the earth, as in the products and minerals which are extracted. For oil, gas-condensate, natural and dissolved gas and the other included useful components both the total and recoverable reserves are estimated and registered.

1.8. The estimation of the mineral resources quality is carried out according to the possible directions of their using correspondingly to the standards and demands of the acting standards and technical conditions and taking into consideration the technology for extracting and processing of the raw materials. At this point the composition of useful and harmful components, the forms of their location and the peculiarities of their distribution in the products of redistribution and waste materials of production are established.

1.9. Estimation and registration of the mass and volume of the reserves and quantitative evaluations of the mineral resources are made in the units of mass and volume. Exploitational reserves of underground waters are estimated and registered, and prognostic resources are evaluated in cubic metres per day. Steam-water mixture in tonnes per day. In industrial waters the quantity of components with commercial value (in tonnes) is established. These components may be obtained in the deposits during the calculation terms of its development without taking into consideration the losses during waters processing. By the deposits of heat-energetic waters, except the exploitational reserves, the heat-energetic power of the field is estimated (in gigajoule, megawatt, tonnes of conditional fuel).

1.10. The application of this classification for different kinds of mineral resources is regulated by the corresponding instructions of the Ukrainian State Commission on the reserves of mineral resources.

2. CLASSES OF MINERAL RESERVES AND RESOURCES BY THE DEGREE OF THEIR STUDYING AND TRUSTWORTHINESS

2.1. Mineral resources that are evaluated based on geological data studying in the areas of the earth, on the earth's surface, in the water and gas sources and on the bottom of water reservoirs as good for commercial exploitation by the conditions of bedding, quantity and quality compose the current mineral resources, and together with the accumulated production — the initial mineral resources of the objects of geological investigation.

2.2. Depending on their determination mineral resources are subdivided into the reserves of mineral resources of the discovered deposits (pools) and the mineral resources of the undiscovered deposits (pools) in the perspective areas of the earth.

2.3. Depending on the degree of geological study completed mineral resources are subdivided into two classes: prospected (proved) and preliminary estimated (probable).

2.4. Prospected (proved) reserves of mineral resources are the reserves with quantity, quality, technological properties, mining-geological, hydrogeological and other conditions of bedding were s[illegible]d in the degree suitable for their commercial exploitation. The main parameters of the p[illegible]cted reserves, which stipulate the project decisions as to the production and proce[illegible] of raw materials and environment prospection, are established by the data of immed[illegible] measurements or investigations done by the uniform volumetrical network in the contours of the deposits with the limited extrapolation, based on the data of geological, geophysical, geochemical and other investigations. The main predestination of the prospected reserves is the projecting of the building of mining enterprises and the fields development.

2.5. The preliminary estimated (probable) reserves of the mineral resources are the reserves of which quantity, quality, technological properties, mining-geological, hydrogeological and other conditions of the bedding that have been studied to the degree suitable for the technical-economical evaluation for either commercial exploitation or test-commercial development. The main parameters of the preliminary estimated reserves of mineral resources, which influence the choice of methods of extracting and processing the war materials, are estimated mainly on the basis of the data extrapolation of measurements or investigations, located in the field limits by rare or uneven network. Extrapolation is grounded by the analogy with the prospected pools (deposits), and also by the data of geological, geophysical, geochemical studying bowels of the earth. The main purpose of the preliminary estimated reserves is the projecting of further prospecting of test-commercial development of the field and its preparation for the commercial exploitation.

2.6. Depending on the degree of geological study and reliability of the mineral resources of perspective underground deposits are subdivided into two classes: perspective and prognosed.

2.7. Perspective mineral resources are the resources of certain geological commercial type, quantitatively estimated based on results of geological study in the limits of productive regions with the known fields of mineral resources of the same geological-commercial type. Perspective resources take into consideration the possibility of discovering of the new deposits (pools) of mineral resources, the existence of which is stipulated by the positive evaluation of the established existance of mineral resources, geophysical, geochemical and other anomalies whose nature and perspectiveness are proven. Quantitative evaluations of the deposit (pool) parameters are determined on the basis of geological interpretation of geophysical and geochemical data or statistical analogy. The main use of the perspective resource estimation is planning prospecting and exploration.

2.8. Prognosed mineral resources are the resources that take into consideration the potential possibility of the fields forming of certain geological-commercial types, based on positive stratigraphical, paleographical, lithological, tectonical, mineraogenic and other preconditions, established in the limits of regional geological structures with undiscovered commercial fields. Quantitative evaluation of the prognosed resources is done on the basis of assumed similar parameters with the analogous geologic structures where discovered deposits of mineral resources of the same geological-commercial type. The main use of the prognosed resources is planning of regional and prognosing-geological works.

2.9. The instructions for using the classification for the deposits of separate kinds of mineral resources define the categories of explored deposits of the mineral resources in the limits of classes by the degree of geological studying and trustworthiness.

3. RESERVES AND RESOURCES GROUPS BY THE DEGREE OF THEIR PREINVESTMENT STUDY

3.1. Rational and effective geological study of the subsurface earth with the aim of discovering or prospecting the mineral resources deposits envisages the optimal succession of geological-exploration works (GEW). In order to determine the expediency of investing the next stage of geological-exploration works or the building of mining enterprise the geological-economical evaluation (GEE) of the objects of geological studying are done. Pre-investment studies of these objects envisage the establishing in detail of mining-geological, technological and technical-economical characteristics of the mineral resources deposits, and also the social, ecological, lawful and other conditions of the field development and the realization of raw materials or the products of their processing.

3.2. The primary geological-economical evaluation (GEE-I) is done for the basing of expediency of the investing the exploration-prospecting works in the earth's areas perspective for discovery of mineral resources. GEE-I is carried out on the grounds of qualitative evaluation of perspective resources and is given in the form of technical-economical suppositions (TESp) as to their possible commercial importance.

3.3. The preliminary geological-economical evaluation (GEE-II) is done with the aim of basing the expediency of commercial exploitation of the deposit (area) of mineral resources and the investing of successive prospecting and preparation for their development. GEE-II is done on the ground of the preliminary evaluated reserves of mineral resources and is given in the form of technical-economical report (TER) on the expediency of further prospecting or test-commercial development of the deposit (area).

3.4. The detailed geological-economical evaluation (GEE-III) is done with the aim of establishing the industrial activity effectiveness of the mining enterprise, which is created on the basis of prospected reserves of mineral resources and includes the technical-economical substantiation (TES) of the standards for their evaluation.

3.5. Thus the mineral reserves and resources by the degree of their preinvestment studying are divided into three groups:

- To the first group the reserves of mineral resources are related reserves, on the basis of which the detailed geological-economical evaluation (GEE-III) is done of the effectiveness of commercial activity of mining enterprise which is projected for their development. The materials of GEE-III, including TES of stable standards for mineral raw materials, underwent the examination and were estimated by the Ukrainian State Commission on the reserves of mineral resources.

- To the second group the reserves of mineral resources are related reserves on the basis of which the preliminary geological-economical evaluation (GEE-II) of their commercial importance is done. The TER materials on the expediency of the field further prospecting, including TES of temporary standards of mineral raw materials, underwent the examination and were approved by the Ukrainian State Commission on the reserves of mineral resources or by the client (investor) of the exploration works.

- To the third group of the resources and reserves of mineral resources are related these, on the basis of which the primary geological-economical evaluation (GEE-I) of the possible commercial importance of the earth's perspective area is done. The TES materials on the expediency of further exploration works and the parameters of recommended standards for mineral raw materials underwent the examination and were approved by the client (investor) of exploration works or the Ukrainian State Commission on the reserves of mineral resources.

4. RESERVES GROUPS BY THEIR COMMERCIAL IMPORTANCE

The classes of mineral resources and useful components are divided into three groups: their commercial importance

a) balanced,
b) conditionally balanced,
c) out of balance.

a) *Balanced* reserves are reserves that at the moment of evaluation accordingly to the technical-economical calculations *may be economically extracted and used with modern techniques and technology of production and processing* of the raw materials, which provide the keeping of demands of the rational using of the *bowels* and the protection of natural environment.

b) *Conditionally balanced* reserves are reserves the effectiveness and production and using of which at the moment of evaluation cannot be precisely established, and also the reserves that correspond to the demands for the balanced reserves, *but cannot be used because* of unsolved, unlawful, ecological and other questions.

c) *Reserves out of balance* are reserves the production and using of which at the moment of evaluation are not economically justified. However, in future they may become of commercial importance.

Only in their balance perspective and prognosed resources are evaluated on the basis of assumed parameters only in their balance part. Out of balance and conditionally balanced components of perspective and prognosed resources are not estimated.

5. GROUPS OF MINERAL RESOURCES DEPOSITS BY THE COMPLEXITY OF THEIR GEOLOGICAL STRUCTURE

5.1. By the complexity of geological structure the deposits of mineral resources or their areas, which are envisaged for the development by individual enterprises, are divided into four groups:

- To the first group belong deposits (areas) of simple geological structures with undeformed or weakly deformed bedding of the deposit, consistent quantitative or qualitative parameters of the mineral resources pools, even distribution of the main useful and harmful components.

- To the second group belong deposits (areas) of complex geological structure with inconsistent quantitative or qualitative parameters of the pools of mineral resources, uneven distribution of the main useful of harmful components.

- To the third group belong deposits (areas) of very complex geological structure with changing quantitative of qualitative parameters of the reserves of mineral resources, very uneven distribution of the main useful or harmful components.

- To the fourth group belong deposits of extremely complex geological structure with sharply changing quantitative or qualitative parameters of the deposit of mineral resources, with absolutely uneven distribution of the main useful or harmful components.

During the determination of the geological structure complexity in the field are used the indices of changing of the main deposit parameters which contain no less than 70% of the raw material reserves.

The instructions for using the classification for different kinds of mineral resources envisage the using of quantitative evaluations of changing of the mineral resources pools parameters and the indices of the raw materials quality for the establishing the groups of complexity of the field (area) geological structure.

6. PREPARATION OF THE MINERAL RESOURCES DEPOSITS (AREA) FOR COMMERCIAL EXPLOITATION

6.1. The state of preparation of mineral resources for commercial exploitation is determined by the decisions of the Ukrainian State Commission on the Reserves of Mineral Resources. The decision is made following examinations of the materials of geological-economical estimations of the deposits (areas) of mineral resources, taking into consideration the conclusions of the clients and performers of geological surveys, the investors of the mining facilities construction, which are projected on the basis of these reserves, and also the demands of the legislation of nature protection and the legislation on the earth's bowels.

6.2. The state of geological study of the reserves of the deposits (areas) mineral resources, which are prepared to the commercial exploitation and are transferred to the users of the bowels must correspond to the following conditions:

6.2.1. Balanced reserves of the main and jointly bedded mineral resources and the available in the adjoining useful components of commercial importance were estimated by the Ukrainian State Commission on the Reserves of Mineral Resources.

6.2.2. The volumes of total reserves and resources of the field (area) in its geological limits were established as to the degree of their geological studying, reserves and resources of the neighbouring undeveloped fields of mineral resources which are taken into consideration at the projecting of construction (reconstruction) the mining objects for the establishing of possible perspectives of the enterprise development, the bordering depth and the development area, the choice of the way of uncovering the pools' mineral resources, the places of laying of the mine shafts, the location of industrial constructions, access roads and so on.

6.2.3. The volumes of balance prospected and preliminary evaluated reserves of mineral resources were established which are used for the projecting of construction (reconstruction) of the mining objects, the possibility of these reserves development is substantiated without damage for the mineral resources pools which are left in the earth's bowels.

6.2.4. The quantity of the prospected reserves of the first class of geological studies provides the activity of mining objects for the period of returning of capital investments into prospecting and commercial exploitation of the field.

6.2.5. The dangerous ecological factors are established and estimated which influence or may influence the state of natural environment and human health during prospecting and development of the field, processing of raw materials, storage of industrial waste; the rational complex of the measures as to environment protection and the people's health is worked out; the background parameters of the environment state are established; preliminary consent are obtained for special use of plots of land with the aim of the mineral resources extraction according to the legislation.

6.2.6. The profitableness of industrial activity of mining object is grounded by technical-economical estimations which is projected on the basis of the reserves of mineral resources established by the State examination, taking into consideration the expenses for additional prospecting of mineral resources, the effectiveness of capital investments into the field (area) development is provided at the level of income average norm.

6.3. For the projecting of construction of mining and processing objects in the field of the first and second groups of the geological structure complexity the prospected reserves of mineral resources of the first class of geological studying are used; in the fields of the third and fourth groups of the geological structure complexity the prospected and preliminary estimated reserves of mineral resources of the first and second class of geological studying in the ratio which is determined by the instructions of the classification as to the separate kinds of mineral resources.

6.4. By the agreement of the interested users of the earth's bowels under conditions of economical risk the transfer of the preliminary estimated reserves of the deposits of mineral resources may be realized before their examination and estimation by the Ukrainian State Commission on the reserves of mineral resources with following obligatory estimation. In such cases the reserves studying, which are transferred to commercial exploitation, may not correspond to the demands of points 6.2 and 6.3 of this classification, on condition that geological studying provides the establishing and evaluation of harmful ecological factors connected with the deposit exploitation, according to point 6.2.5.

6.5. In the deposits which are brought into development the additional prospecting and exploitation prospecting are carried out.

6.5.1. The additional prospecting of the developed deposits is carried out in their insufficiently studied parts (flanks, deep or upper horizons, separated areas, etc.) and is done consequently according to the plans of productive works.

6.5.2. The exploitation prospecting which leaves behind the development of productive works, must specify the data on morphology, inner structure, conditions of the pools bedding and development and the quality of their mineral resources by data of drilling the additional wells and of hole-making of the mining-preparatory and other workings. The exploitation prospecting, which accompanies the productive works, must specify the quantitative and qualitative indices of the mineral resources pools by data of drilling and investigations in development and regime wells, investigations in the cleaning mining workings, etc.

6.5.3. In the result of carrying out the additional prospecting and exploitation prospecting of the deposits (areas) of the developed mineral resources the transferring of preliminary evaluated reserves into prospected ones, and also the calculation and registration of the established reserves are made.

6.6. In the developed deposits of mineral resources the uncovered, prepared, ready for extraction and also being present in the protecting pillows of mining-capital and mining-preparatory workings of the reserves of mineral resources are estimated and registered separately with their dividing into classes and groups according to the degree of geological studying and their commercial meaning.

6.7. The recalculation and the examination of the reserves of mineral resources are made by the State in the following cases:

– if in the result of mining or additional exploration works or the investigations as to the pool regime of mineral resources in the developed deposits the summary prospected balance reserves increases for more than 50% in comparison to the preliminary evaluated ones by the Ukrainian State Commission on the reserves of mineral resources, or if the written-off and envisaged for the writing off the prospected reserves as those that were not proved or inexpedient for production by technical-economical (mining-technical) reasons, exceed the norms established by legislation;

– if the revision of the standards demands and technical conditions as to the quality and quantity of mineral resources, the technology of their processing leads to decreasing of summary balance prospected reserves of the deposits of mineral resources of more than 20% or their increasing for more than 50%.

– if the exceeding of real terms of exploitation of the deposit (area) reserves of mineral resources over the adopted ones at heir State examination and evaluation is reached in the extent that leads to the reconstruction of mining objects in connection with the changing of exploitation conditions.

7. CODIFICATIONS SYSTEM USED IN THE CLASSIFICATION OF THE MINERAL RESERVES AND RESOURCES

As shown in Table I, classified mineral reserves and resources are identified by three-numerical codification. The first number indicates the degree of commercial importance of mineral reserves. Number 1 means "balance reserves", number 2 — "conditionally balance reserves" and number 3 — "outbalance reserves".

The third code numbering indicates the degree of geological investigation and trustworthiness of the mineral reserves and resources. Number 1 means "prospected reserves", number 2 — "preliminary estimated reserves", number 3 — "perspective resources", and number 4 — "prognosticated resources".

The second code numbering indicates the degree of technical-economical investigation of the mineral resources and detail geological-economical evaluation of the deposit (area). Number 1 means that the mineral resources has undergone detailed geological-economical evaluation (GEE-I) and were estimated by the State Commission of Ukraine for Reserves of Mineral Resources on the basis of the technical-economical substantiation (TES) of the standards for reserves evaluation. Number 2 means that mineral resources has undergone preliminary geological-economical evaluation (GEE-II) and were tested by the State Commission of Ukraine for Reserves of Mineral Resources or by client (investor) on the basis of technical-economical report (TER) on their readiness for commercial development. Number 3 means that mineral resources has been subjected to initial geological-economical evaluation (GEE-III). Number 0 indicates that geological-economical evaluation was never carried out.

8. GENERAL REMARKS RELATED TO THE CLASSIFICATION PROJECT

The project of Classification of the mineral reserves and resources of the State Fund of Ukraine foresees the solution of the following main tasks:

- adaptation of the existing system of estimation and registration of the mineral reserves to the conditions of the transitional period of market economics and legislation of Ukraine;
- ensuring the possibility of the Ukraine Classification for inclusion to the international system of reserves reporting;
- ensuring the possibility of a Classification that can be used for all kinds of mineral resources;
- preservation of the clauses of the existing classification which do not contradict with the new economical and political conditions.

The Classification is based on the most general criteria of investigations and trustworthiness of reserves and resources, which are common for all kinds of mineral resources. It is envisaged that the instructions in using the Classification for certain types of mineral resources will include questions related to the reserves investigation in sufficient details that will allow independent estimate.

The requirements related to the preparation for commercial exploitation of the deposits may also be given in the instructions on the use of the Classification and the exact regulations related to the development of technical-economical substantiations (TES), technical-economic reports (TER), technical-economic suppositions (TESp). All of these are still being prepared.

TABLE I. CORRELATIONS OF UKRAINIAN CLASSIFICATION OF RESERVES AND RESOURCES OF MINERAL RESOURCES WITH INTERNATIONAL FRAMEWORK FOR CLASSIFICATION OF RESERVES AND RESOURCES

<table>
<tr><td rowspan="2">UN International →
Framework
↓</td><td></td><td>Detailed exploration</td><td>General exploration</td><td>Prospecting</td><td>Reconnaissance</td></tr>
<tr><td>Ukrainian system</td><td>Class 1
explored</td><td>Class 2
preliminary estimated reserves (probable)</td><td>Class 3
prospective resources</td><td>Class 4
forecast resources</td></tr>
<tr><td>Feasibility study</td><td>detailed preinvestment estimation (TES)</td><td>1. (1.1.1)
2. (1.1.2)
3. (1.1.3)</td><td colspan="3">usually do no</td></tr>
<tr><td>Prefeasibility study</td><td>preliminary preinvestment estimation (TER)</td><td>1. (1.2.1)
2. (1.2.2.
3. (1.2.3)</td><td>1. (2.2.1)
2. (2.2.2)
3. (2.2.3)</td><td colspan="2">singled out</td></tr>
<tr><td>Geological study</td><td>primary preinvestment estimation (TESp)</td><td></td><td>1-3 (2.3.1-3)</td><td>1 (3.3.1)</td><td>1 (4.3.1)</td></tr>
</table>

Mineability

UN Framework

1. Economic
2. Marginally economic
3. Subeconomic

1-3. Economic-subeconomic

Commercial meaning

Ukrainian system

1. Balanced
2. Conditionally balanced
3. Out of balance

1-3. Indivisible balance and out of balance

(1.1.1) —
Figure indices of reserves and resources

TABLE I. COMPARATIVE DESCRIPTION OF CATEGORIES OF URANIUM RESERVES AND RESOURCES IN KAZAKHSTAN FOR EXTRACTION BY MINING AND ISL METHODS

Resource and reserves categories	Prospecting work stage		Estimation method		Kinds of analyses, measurement, determinations		Dimensions and shapes of orebodies		Localization condition genesis	
	Mining method	Well ISL method	Mining method	Well ISL method	Mining method	Well ISL method	Mining method	Well ISL method	Mining method	Well ISL method
P_1 Speculative (prognosticated) resources	Prognosticated prospecting works	Prospecting-estimating works	Uranium mineralization quantity and quality estimated using geological, geophysical and geochemical results, and also by geological extrapolation	Uranium mineralization quantity and quality estimated from drill hole well profiles with core sampling Distance between well profiles is 3200–1600 m, and between wells within ore zone it is 50–100 m	Ore material analysis is not carried out because of absence of samples	Core samples are used for determination from ore intervals of enclosing sedimentary rocks granulometric composition, carbonate content, uranium and radium content, and of 28 elements by spectral analysis Volume weight, humidity and mineralogical composition are determined	There are various body shapes (strata, stockworks, lenses, veins) Orebody dimensions are given within large ranges	Belt-shaped ore bodies have widths up to 1000 m and lengths of tens km	Usually the deposits of hydrothermal genesis of the endogenous group, mineralization occurs in rock	Hydrogenic genesis deposits of exogenous group "Sandstone-" type Mineralization occurs in unlithified, very permeable rocks
C_2 Previously estimated reserves	Prospecting-estimating, estimating works, previous exploration	Estimating works and previous exploration	Shape, dimensions, internal structure of uranium orebodies and their bedding conditions are estimated from geological and geophysical data, confirmed by a single drill hole or mine working	Uranium orebody quantity and quality estimated from drill hole profiles with core sampling (on based previous stage profiles continuity), located at 800–400 m with the distance between the holes of 100–50 m	All ore intervals are sampled Chemical and radiometric analysis for uranium, thorium, radium, technological ores laboratory investigations, and radioactive equilibrium coefficient determinations ar done	In addition to the previous stage analysis and measurements, ore laboratory investigations (uranium, extraction coefficient, type of leaching), filtration coefficient are also determined	--"--	--"--	--"--	--'--

Introduction of the proposed Classification for each groups of mineral commodities has to be done gradually after instructions on the use of the Classification system has been prepared.

The groups of mineral commodities, for which preparation of the instructions on the application of the Classification is anticipated, are the following:

1. Coal, petroliferous shales
2. Oil and gas — is being developed
3. Underground waters
4. Ferrous and non-ferrous metals — is being developed.
5. Noble metals
6. Rare, rare-earth, dispersed metals
7. Radioactive elements
8. Raw materials for metallurgy — is being developed
9. Mining-chemical raw materials — is being developed
10. Building and facing raw materials
11. Jewelry, optical, radiotechnical raw materials.

In contrast to the existing Classification the new system is hoped to achieve:

- estimation and registration of the country's mineral reserves and resources, taking into consideration losses during production and processing;

- differentiation of the reserves according to their geological trustworthiness and commercial values and separate them according to their degree of preinvestment investigation.

CHARACTERISTICS OF URANIUM RESERVES AND RESOURCE CATEGORIES IN KAZAKHSTAN FOR VARIOUS METHODS OF EXTRACTION

(Summary)

XA9847836

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During the previous meeting (April 1995), Kazakhstan's representative had indicated the problem connected to uranium resources of the same category that can be produced by different methods of mining (conventional and in situ leaching). To facilitate understanding on this discrepancies, a description on the methodology of preparing reserves and resources categories that was carried out during the USSR period, and still used in Kazakhstan, is shown in Table I. It should be kept in mind that in Kazakhstan, its large amount of uranium resources (more than 1 million tonnes) was estimated and explored in accordance to the methodology for in situ leaching type of uranium production.

At present, the State Committee on Reserves of the Republic of Kazakhstan is in the process of preparing the new common minerals reserves and resources classification. The class categories (A, B, C1, C2, P1, P2 and P3) will remain the same. However, their characteristics are being changed significantly. Promulgation of the new classification is planned for the end of 1996. Based on this new classification, in 1997, they will prepare additional instructions for separate mineral commodities, uranium included, taking into consideration the recommendations of the IAEA's consultants meeting on this subject.

TABLE 1. (Cont.)

Resource and reserves categories	Prospecting work stage		Estimation method		Kinds of analyses, measurement, determinations		Dimensions and shapes of orebodies		Localization condition genesis	
	Mining method	Well ISL method	Mining method	Well ISL method	Mining method	Well ISL method	Mining method	Well ISL method	Mining method	Well ISL method
C_1 Explored reserve	Previous and detailed exploration	Detailed exploration	Uranium orebody dimension and shape are determined by mine workings or drill holes along grids (depending on deposit complexity) to give internal composition, shape and technological properties etc of ore	Uranium mineralization quantity estimation is carried out using drill hole profiles (based on previous stage profiles continuity) drilled without core sampling, on 200 m spacing with 50–25 m between holes	In addition to the previous stages, pilot technological ore investigations are carried out	In addition to the previous stage, analysis and measurements, field testing of in situ leaching and neutron logging is carried out in wells without core sampling	--"--	--"--	--"--	--"--

TECHNICAL-ECONOMIC EVALUATION OF URANIUM RESERVES IN THE DIAMO COMPANY, STRÁŽ POD RALSKEM (CZECH REPUBLIC)

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XA9847837

Abstract

Changing economic conditions in the Czechoslovakian (CSFR) economy (in 1992) made it necessary to realign exploitation of uranium in the country, taking into consideration economical, and environmental factors. This was done partly through mathematical-geological modelling. This analysis, which take into account mining practice and costs, involved reevaluating the uranium resources. The report describes how this was accomplished. It also describes how the uranium classification system used in the CSFR, which is based on the categories A,B,C1,C2,PI and P2, compares to the IAEA system.

INTRODUCTION

DIAMO company in Stráž pod Ralskem is a state enterprise, the main activities of which are involved in exploration, mining, and processing of uranium ore. New economic conditions connected with the transformation of the Czechoslovak economy to the market economy bring the essential change in the view on the uranium deposits use. The former way exploitation of the mostly unprofitable deposits by the strong subvention state support is being substituted by the reduction activities aiming to the use only of those raw material resources which are profitable and favourable for the state. This trend touches the more DIAMO company, the more this branch was preferred by really unlimited concentrate export to the former USSR.

As the request on Czechoslovak uranium mining is limited by needs of the Czechoslovak nuclear energetics, the present situation significate large cutdown of uranium mining in CSFR. During the last two years mining has finished on deposits Vitkov II, Dylen, and Pribram ore district. Regarding to the fact, that the finishing of exploitation of deposit Zadni Chodov is considered at present, there are only deposits in Hamr district (Hamr, Stráž) and Rozna to ensure fuel for the Czechoslovak nuclear plants. Also for it is necessary to change our view on the use of these three uranium deposits completely. Besides the economical aspect we must take into account environmental affects of mining and uranium processing. New solution of these problems is complicated; it leads to the mathematic-geological models.

MATHEMATICAL MODELING OF DEPOSITS

At the end of the 1980s the mathematic-geological models of two basic types of uranium deposits were solved. The Rozna deposit [2] was chosen as a zone-deposit representative and Hamr deposit [3] as a sandstone type deposit representative. Practical application and progressive improvement of modeling methods by regular and variant estimation of reserves had done till the 1990. It enabled to realize the next stage of their development, the stage of an economic evaluation. Application of the principles of mathematic modeling has brought a new system approach to the solution of complex reserves evaluation problem. According to the example of Hamr deposit the whole process of evaluation may be divided into four phases.

The mathematic-geological model phase

It is the first phase, transforming necessary geological data of the deposits databank (title, coordinates, thickness, and linear reserves of each intersection or sample point) into the geological model using the mathematical algorithms selected. With the help of geological marginal parameters (i.e. minimum marginal grade in sample, minimum marginal grade in the marginal part of the orebody, correction on contents of technological impurities (Zr), marginal thickness of waste interlayer) the variant calculation of geological reserves by means of interpolation method IDS (inverse distance squared) is performed. In this way the data of geological reserves of cells (elemental microblocks) are prepared for the further calculations.

Technological model phase

The phase transforms the the geological orebod y modeled onto the form responding to the demands of the exploitation technology used. By means of marginal parameters of the selected exploitation technology (minimum and maximum operating height, thickness of waste interlayer, grade of uranium in technological brushing, rate of the waste material stowed in rooms) the minable reserves are determined.

Economic evaluation of minable reserves phase

It is performed as the next stage for the calculation of reserves of single cells. The method using limit costs is applied for the economic evaluation [1, 6]. This method is based on the ability to appreciate single mining blocks or their parts depending on the development, preparatory and operating cost, filling of the worked-out room, and also on the transport and processing of the ore. This fact is improved by the final result of former phases, i.e. the method of cells. Minable reserves of single cell are economically evaluated on the costs necessary to yield the final concentrate incl. the filling of worked-out room and according to the concrete situation of development, preparatory and operation works in the given block. If we divide the costs determined this way by the calculated metal quantity in the concentrate, we will get the unit costs per 1 kg U.

Phase of final reserves evaluation of a deposit

Final work involves grouping of all cells used for evaluation of the deposit or its part to the classes corresponding to the unit costs, ascendent sorting of these groups, and construction of the cumulation cost diagram. For separate cumulation cost curve are considered unit costs of determined cumulated quantity and unite costs of joined class. Unit costs of the last joined class, which cumulated unit costs are much lower for than the stated price of metal increased by the necessary profit, are limitation unit costs (LUC). The value of LUC differs the economically exploitable reserves from other reserves. From separate files of economic evaluation on the plotter there are shown monitors of unit costs in microblocks.

TECHNICAL-ECONOMICAL EVALUATION OF RESERVES ON DEPOSIT STRÁŽ

The deposit Stráž is exploited by in situ leaching (ISL) mining technology. Methodics of technical-economical evaluation is conformed to this technology. Geological reserves (see 2.1.) are calculated for all ore-bearing interval with regard to particular division to litostratigrafic horizons (3-5 layer model). In exploratory net of core wells are determined theoretical yields for individual horizons on the base of technological valuation of samples of drill core.Technological classification is made according to several criteria, the most important are leachibility of ores, consumption of sulphuric acid, permeability and vertical position within the formation. Vertical profile is devided to geotechnological layers, with separate yields of uranium for standard technological conditions. Recounted yields corresponding to geological intervals of litostratigrafic layers are in the second step interpolated for other (non-core) wells with only known thickness and distribution of uranium in the particular lithostratigrafic horizons. Recoverable reserves are calculated with regard to theoretical and interpolated yield.

Optimal calculations, based on mathematical modelling of underground processes, showed that it is efficient to differentiate technological process ISL in accordance with ore grade and technological properties of separate wellfields. For determination of specific mining conditions was developed methodic for economical evaluation of reserves. The methodic employs also results of long term laboratory leaching tests and makes possible determination of reaction kinetics. For every separate area are calculated leaching results for several regimes, different in batch of sulphuric acid and intensity of solution's circulation. On the base of results is determined optimal technological process ISL for separate wellfields. The difference between separate regimes is considerable. For standard and substandard wellfields is batch of sulphuric acid 3–5 times less than for rich wellfields. With this fact connects also variability of expected yield in comparison with static estimation. The advance of this dynamic economical evaluation of reserves is possibility to react on changes of prices, wages, financial and tax orders. Computed values are used for planning and operation ISL. They are used for determination of economical recoverable reserves on separate wellfields, but it is necessary to recalculate them in dependence on changes of economical entries.

TECHNICAL-ECONOMICAL EVALUATION OF RESERVES ON THE DEPOSIT ROZNA

Creation of mathematical model of reserve calculation on the deposit Rozna comes out of the following presumptions:

– orebodies are controlled by faults and they are limited by them. The area extend prevails significantly over the thickness. Orebod ies are characterized by a high variability of thickness and grade of useful component.

– points of intersections of exploration works (holes, profiles of radiometric sampling) are the main information sources concerning the distribution of parameters.

The basic method of geological reserves estimation is the principle of analogy between parameters gained during the exploitation and by the exploration works in neighbourhood of the area where reserves are calculated on. The algorithm of the calculation is put down in the way to consider the width of area exploration and also the extend of the area where the reserves are determined. The estimation of calculation parameters from input data distributed inside of exploited block are solved for individual variants, also in combination with farther surroundings.

Input parameters for economically exploitable reserves calculation are besides limiting direct costs per 1 kg U in chemical concentrate also the minimum marginal balance sample content, minimum linear marginal sample reserves, minimum grade of U in the marginal mining part and maximum thickness of interlayer of waste or unbalanced ore.

The calculation is based on the evaluation of limit variable costs in the block under operation The costs depending on the extend of realized mining works (connected with deposit preparatory works, mining and ore processing) as well as other costs (which are not depending on the extend of exploitation and processing), are appreciated separately.

		———> decreasing confidence in estimates					
RESOURCE CATEGORIES		A	B	C1	C2	P1	P2
ECO-NOMIC ESTI-MATE	EKONOMIC C <= x_1 CSK						
	SUB-EKONOMIC C > x_1 CSK C <= x_2 CSK						
	NON-EKONOMIC C > x_2 CSK						
EKVIVALENT OF CLASSIFICATION IN FRG (URANIUM 1990, AGENCE POUR L'ENERGIE NUCLEAIRE, page 24, 25)		PROVEN	PROBABLE		POSSIBLE	PROGNOSTICATED	SPECULATIVE

C = cost of gained metal in concentrate x_1, x_2 = limit costs for concrete period

FIG. 1. Classification of uranium resources in the Czech and Slovak Republic; comparison with other systems (1992).

Invasion of new methods of economic estimate into the reserves calculation means fundamental assessment of the term of the reserves balance. The former classification of the reserves into the balance and the nonbalance ore came out mainly of general conditional criteria, it means experimentally determined limits of marginal values of calculation parameters without regarding to the real ore processing and exploitation costs. It is diputable to consider original "nonbalance ores" in balance sheet on account of relatively low value of these marginal parameters.

As of the economic estimate of reserves, it is possible to consider for the main balance criterion the limit unit costs (LUC). The value of LUC will divide the exploitable (mineable) reserves characterized by unit costs (UC) of cells into reserves:

economical	$(UC \leq LUC)$
subeconomical	$(LUC < UC \leq LUC \cdot 1.5)$
noneconomical	$(UC > LUC \cdot 1.5)$.

The selected terminology is used to the purpose to emphasise the economical approach to the evaluation of reserves in contrast to the former balance/nonbalance classification which missed this economical classification. Category of subeconomical reserves characterizes the reserves which can be prospective in case if the ore sale price suddenly increases or improvement of mining or processing technology come true. The upper limits of that categories were determined experimentally and it shall become more precise during the further calculations.

Besides the above mentioned economical dimension there is a second dimension of reserves classification expressing the rate of exploration and paralelly also the reliability of performed evaluation characterized by generally known categories A, B, Cl, C2, Pl, P2. The equivalents of them you can see in appraisal of U ores reserves in Germany [5]. According to the approved methodic for the reserves calculation used for the North Bohemian Createaceous deposits [4] individual categories are defined by the total error of reserves [3] and also by a verbal description of other limiting conditions. A comparison resource classes used int the Czech and Slovak Republic with other methods is given in Figure 1.

The two-dimensional classification of reserves meets all requests of a miner on raw material basis of a mine. It provides sufficient basis for strategic evaluation of state raw material balance sheet for the state authorities.

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SOME SUGGESTIONS RELATED TO THE HARMONIZATION OF URANIUM RESOURCE CLASSIFICATION

(Summary)

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The B and C1 categories of uranium reserves that are characteristic for Uzbekistan can probably be compared to the explored reserves based on IAEA classification. The first (B) category, in deposits of the sandstone type, are from areas where full scale exploration (geotechnological) programme has been carried out (using drill hole grid of 50 × 25 m). The C1 category, also in deposits of the sandstone type, are from areas where the drill hole grid are of 200 × 50 to 100 m and sometimes as close as 100 × 25 to 50 m.

Reserves of C2 category, referred to as preliminary estimated reserves, are found in sandstone type deposits where drilling programme followed a 400 × 50 to 100 m grid and sometimes a 200 × 50 to 100 m grid in the case where the deposit has a more complex morphology. According to the stages accepted in the Republic, the stage of preliminary estimate is followed by detailed estimate. The advisability of conducting detailed estimate is governed by the result of works in the previous stage. From this explanation it would be appropriate to classify the reserves of C2 category as a preliminary estimated additional reserve of category I ("PODZ-I" n Russian), although a large part of C2 reserves was already included in the explored reserves.

For the preliminary estimated additional reserves of category II ("PODZ-II" in Russian) it is suggested to include Pl category, which is the predicted resources in areas that are under current exploration activities. It is further suggested to include P2 resources into category of prospective deposits ("PZ" in Russian), that might occur in area within known uranium districts where new reserves of specific types of deposits might be found or in new areas with similar geological environment that is known to contain uranium deposits.

For the technical and economic evaluation (called "TEO" in Russian) it is advisable to conduct the required works and prepare a preliminary "TEO", which was used in the former USSR, and is still used during the study of new area with no known uranium deposit characteristic. During the exploration and development works in the known regions such as in Central Kyzylkum province, the role of preliminary evaluation is minimal. A good geological study of territory of the province, and the availability of sufficient number of standard facilities might provide a situation where the evaluation stage of "TES" and even "TED" could be eliminated. The result is a reduction of the expenses of test works and at the same time reduces the time to start industrial development.

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Appendix I

NEA/IAEA CLASSIFICATION SCHEME FOR URANIUM RESOURCES

Decreasing Economic Attractiveness

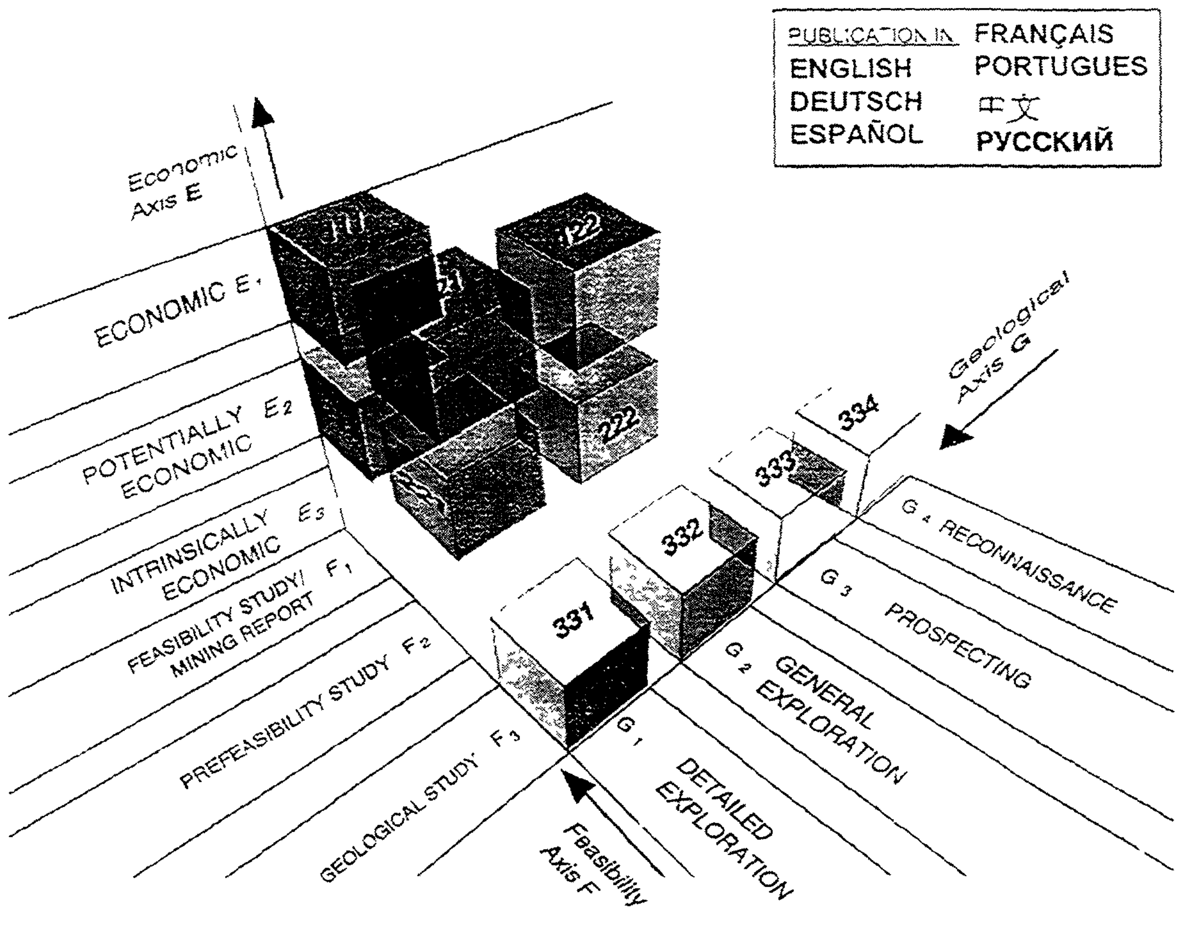
Recoverable at Costs				
$130-$260/kg U	REASONABLY ASSURED RESOURCES	ESTIMATED ADDITIONAL RESOURCES I	ESTIMATED ADDITIONAL RESOURCES II	SPECULATIVE RESOURCES
$80-$130/kg U	REASONABLY ASSURED RESOURCES	ESTIMATED ADDITIONAL RESOURCES I	ESTIMATED ADDITIONAL RESOURCES II	
$40-$80/kg U	REASONABLY ASSURED RESOURCES	ESTIMATED ADDITIONAL RESOURCES I	ESTIMATED ADDITIONAL RESOURCES II	SPECULATIVE RESOURCES
$40/kg U or less	REASONABLY ASSURED RESOURCES	ESTIMATED ADDITIONAL RESOURCES I	ESTIMATED ADDITIONAL RESOURCES II	

Decreasing Confidence in Estimates

Appendix II

UNITED NATIONS INTERNATIONAL FRAMEWORK CLASSIFICATION FOR RESERVES/RESOURCES — SOLID FUELS AND MINERAL COMMODITIES

United Nations Economic Commission for Europe
Committee on Sustainable Energy



The UN Framework Classification has been developed as an international scheme for assessing solid fuel and mineral deposits under market economy conditions The initiative was undertaken by the United Nations Working Party on Coal, recognizing the need for an internationally acceptable reserve/resource classification system, particulary in view of the current transition of central and eastern European countries to market economy conditions

UN International Framework → ↓	National System → ↓	Detailed Exploration	General Exploration	Prospecting	Reconnaissance
Feasibility Study and/or Mining Report		1 (111) 2 (211)		usually not relevant	
Prefeasibility Study		1 (121) 2 (221)	+ (122) + (122)		
Geological Study		1-2 (331)	1-2 (332)	1-2 (333)	? (334)

Economic Viability Categories 1 = economic 2 = potentially economic 1-2 = economic to potentially economic (intrinsically economic) ? = undetermined
Classification Code (111), =(E F G) where E = degree of Economic Viability F = stage of Feasibility Assessment and G = stage of Geological Assessment

The numerous classification systems currently in use are based on differing principles and have differing terms and can thus only be harmonized by means of a supra-national framework system During the last four years over sixty ECE and non-ECE countries participated in compiling this new classification in collaboration with the Ferderal Institute for Geosciences and Natural Resources (BGR) The system has been finally approved by UN/ECE at its 50th anniversary session in April 1997 The system is highlighted as follows

Objective

- internationally applicable and acceptable
- facilitate international trade and cooperation
- link "market economies" and "economies in transition"

Features

- market economy criteria
- generally understandable and simple to use, directly reflects procedures used in practice, accommodates results available
- incorporation of existing terms; retaining them and making them comparable and compatible
- flexible in application; usable at company/institutional, national and international level, specific mineral requirements accommodatable
- codification for unambiguous identification of Reserve and Resource Classes
- uniform use of terms Reserves and Resources based on CMMI Terminology

How it works

categorization according to

- Geological Assessment

  Reconnaissance
  Prospecting
  General Exploration
  Detailed Exploration

- Feasibility Assessment

  Geological Study
  Prefeasibility Study
  Feasibility Study/
  Mining Report

- Economic Viability

  economic
  potentially economic
  intrinsically economic

Future Development

- translation into major world languages
- three-year trial in practice and refinement of system

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Appendix III

TERMS AND DEFINITIONS USED IN THE RUSSIAN FEDERATION AND UKRAINE

active resources. Resources that are producible at a cost of < $80/kg U, therefore presently may be considered as potentially economic.

explored. Evaluated.

not active resources. Resources that are producible at a cost of > $80/kg U, therefore presently considered as non-economic.

on balance. Economic.

out of balance. Non-economic.

perspective resources. Projected resources.

preliminary evaluated. Detailed pre-investment evaluation (Shumilin).

prognosticated resources. Speculative resources.

sub-balance. Sub-economic.

TED/TER. Technical and economic assessment; of possible future mineability. It defines B, C1 resources, decision on preliminary balance amount, approximately equal to potentially economic/economic decision.

TED. Technical and economic assessment of present mineability; primary pre-investment estimation. It defines resources equal to a feasibility study or mining study resulting in resulting in presently not extractable balance amount and extractable balance amount = industrial reserves.

TES. Evaluation of economic potential; preliminary pre-investment evaluation.

TESP. It is conducted after geological exploration defining C2, P1 resources, decision on go/no go.

UKRAINE SYSTEM:

balance uranium resources = economic = < $80/kg U

C1 = explored resources = RAR

C2 + P1 = preliminary estimated resources + EAR I

conditionally balance resources = subeconomic = < $130/kg U

out of balance resources = subeconomic = > $130/kg U

P2 = perspective resources + EAR II

P3 = prognosticated resources = Speculative Resources (SR)

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