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PREFACE

While working at IIASA from April 17, 1978 to July 28, 1978, Dr. A.M. Perry made a number of contributions to the evolving thoughts of the Energy Systems Program of IIASA. In particular, he brought out the point that various official compilations of uranium reserves were inadequate for estimating resources on which nuclear futures could be planned. The relatively transparent reasoning he used to arrive at a uranium resource estimate is documented here, to serve as background for the briefer exposition that is being incorporated into the Nuclear Chapter of the forthcoming book of IIASA's Energy Systems Program "Energy in a Finite World".

ABSTRACT

Official estimates of world uranium resources (e.g. OECD's estimate published in 1977 of about 4 million metric tons) appear to be too low by a rather large factor, i.e. five or more. A procedure is needed for adjusting these estimates to obtain numbers more suitable for analysis of broad energy development strategies. In this paper we adopt such a procedure, scaling upward from estimated resources in the United States on the basis of equal resources per unit area. Some justification for this procedure is found in data given by OECD for individual countries. The resulting estimate of commercially useable global uranium resources is in excess of 20 million tons of uranium.

World Uranium Resources

1. INTRODUCTION.

The three issues of future growth of nuclear power, of uranium resources, and of strategies for nuclear reactor development and use are critically linked. Concurrent assumptions of high growth rates of nuclear capacity and of a small useable uranium resource base have sometimes been used to justify recommendations for a very aggressive program of breeder reactor development and deployment. Conversely, assumptions of slow growth and abundant uranium have led to the conclusion that breeders will not be needed for several decades and possibly not at all (if, in the meantime, an alternative such as fusion or solar energy should prove to be superior). In this memorandum we review the principal estimates of global uranium resources, find them unsuitable for analysis of nuclear power strategies, and adopt a procedure for obtaining estimates more appropriate for this purpose.

2. OFFICIAL ESTIMATES OF WORLD URANIUM RESOURCES.

The principal estimates of world uranium resources that have the character of official estimates are:

Joint estimates published by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development and by the International Atomic Energy Agency (OECD/IAEA); the latest is a series of reports on this subject published in December, 1977 [1];

The World Energy Conference (WEC); the latest report on this subject was published in November, 1977 [2].

These two estimates are not independent, and indeed the two reports present virtually identical data. These estimates are summarized in Table 1a.

Table 1a.
Estimated World[a] Resources of Uranium[b]
(10^3 tons[c] of Uranium)

	Reasonably Assured Resources[c]	Estimated Additional Resources[d]	Sum
< \$80/kg U[e]	1650	1510	3160
\$80 - \$130/kg U[f]	540	590	1130
SUM (< \$130/kg U)	2190	2100	4290

[a] Excludes Eastern Europe, the Soviet Union, and China, as well as many other countries for which data were not available.
[b] Source [1].
[c] Tons means metric tons
[d] See text for a discussion of these resource categories.
[e] \$80/kg U ≈ \$30/lb U_3O_8 "forward cost" (see text for definition).
[f] \$80 - \$130/kg U = \$30 - \$50/lb U_3O_8.

The OECD/IAEA (WEC) estimates are listed in two categories with respect to degree of assurance. The cost categories are the same as those used by the United States Department of Energy [1], i.e. ≤ \$30/lb U_3O_8 (\$80/kg U) and \$30 - \$50/lb U_3O_8 (\$80 - \$130/kg U). These are so-called "forward costs". They include estimated production costs not yet incurred (in constant dollars), but do not include past expenditures for exploration or for development of mines and mills, and they do not include an allowance for taxes or profit. Thus, they do not directly represent the prices at which the material would be sold. These are sometimes estimated to be approximately 1.6 times the "forward costs"*, giving limits for "long-run marginal cost"

*A discussion of the relation between forward costs and uranium prices may be found in the U.S. Nuclear Regulatory Commission's "GESMO" report [3].

categories of roughly $125/kg U and $200/kg, respectively ($48 and $80/lb U_3O_8).

With respect to the degree of assurance that the estimated amounts of uranium actually exist, the two OECD/IAEA categories are defined as follows [1]:

> "Reasonably Assured Resources" refers to uranium in known deposits and calculated to be recoverable within the given costs with current technology. The estimates are based on specific sample data and measurements of the deposits. A high degree of assurance attaches to this category, which is considered as "Reserves".
>
> "Estimated Additional Resources" refers to uranium (in addition to Reasonably Assured Resources) that is expected, mostly on the basis of direct geological evidence, to occur in extensions of well-explored deposits, in poorly-explored deposits, or in undiscovered deposits that are believed to exist along well-defined geological trends with known deposits. The estimates are based primarily on knowledge of deposit characteristics as determined in its best known parts or in similar deposits. The degree of assurance is less for these Estimated Additional Resources than for reserves.

The resource estimates in both categories are expressed in terms of recoverable uranium after making allowance for ore dilution and for mining and milling losses [1].

The uranium resource estimates presented by OECD, when viewed in the context of global energy supplies over the next half-century or more, appear to be very restricted in scope and definition.

1. Large areas of the world--in fact more than half of the earth's land area--are not included at all in the OECD/IAEA

estimates because data were not available.

2. Among the areas that are included, there are very large differences in the intensity of uranium exploration efforts undertaken thus far. However, even in poorly-explored areas, the limited efforts that have been made appear in many cases to have been quite successful, in relation to the level of effort. One is therefore encouraged to suppose that further exploration will disclose significant additional uranium deposits.

3. Even in the areas that have received the most intensive exploration efforts, the resource estimates presented by OECD are largely limited to the tangible results of exploration already carried out. Major categories of potential resources that may be identified ab initio or that may be better defined by future exploration activities have a lower degree of assurance than Reasonably Assured and Estimated Additional Resources, and are not included in the OECD/IAEA estimates.

4. Although the forward cost categories used in the OECD report [1] have been revised from the previous report (1975) (mostly in order to allow for escalation in production costs), they still correspond to relatively high grades of uranium ore. It seems clear that resource evaluations in most countries have concentrated on deposits with propects for commercial exploitation in the near term (i.e. within the next 15 - 20 years). Resources marginally inferior to the grade categories adopted are not only excluded from the tabulations, but appear to have received comparatively little attention.

In addition to these restrictions, which open the possibility of significant upward revisions in the OECD/IAEA estimates, it may be noted that large known deposits of uranium of substantially inferior grade are excluded from consideration. While it is not clear at present whether such deposits (e.g. lignites, marine black shales) will ever be commercially exploited for their uranium content, they do represent in the aggregate a very large potential additional resource.

It is the purpose of this memorandum, therefore, to present in some detail the bases for the foregoing observations. We then adopt and apply a procedure for obtaining estimates of commercially-useable world-wide uranium resources which we believe to be more suitable for analysis of broad energy-development strategies.

3. OBSERVATIONS ON THE OECD/IAEA ESTIMATES [1].

OECD and IAEA compiled their estimates of world uranium resources from reports submitted by governments of individual countries in response to inquiries by OECD and IAEA. While much of the exploration work and evaluation has been performed by private companies, the results of this work, where available, have been funneled to OECD/IAEA via the government reports and conform to the interests and reporting standards of the individual countries. Some 50 countries (representing approximately 50% of the earth's land area) submitted reports. Of these, 32 countries (40% of land area) reported uranium (usually very small amounts) in at least one of the four categories (two cost categories × two assurance categories). These 32 countries and their reported uranium resource estimates are listed in Table 1b, taken from Reference 1.

Several features of the data presented in Table 1b and in Reference 1 are worthy of comment.

1. Almost 80% of the lower cost reserves (A_I) and of the total estimated resources are reported by four countries (the United States, Canada, South Africa, Australia).

2. Many countries, in reporting their estimated uranium resources, appear to have concentrated on lower-cost reserves (category A_I in Table 1b), giving relatively little attention to either higher-cost reserves (A_{II}) or to Estimated Additional Resources. In several important cases, the lower-cost reserves constitute a major fraction of the total estimated resource, e.g. Niger (75%), South Africa (73%) and Australia (84%).

Table 1b. Estimated World Uranium Resources[a,b,c]
(10^3 metric tons of Uranium)

	A=Reasonably Assured Resources			B=Estimated Additional Res.			A+B=Total Est. Resources			$\frac{\Sigma_{AB}}{\Sigma_{World}}$ x 100 (%)
	I <$80/kg	II $80-130	Σ_A <$130/kg	I <$80/kg	II $80-130	Σ_B < $130/kg	I <$80/kg	II $80-130	Σ_{AB} <$130-kg	
Algeria	28.0	0	28.0	50	0	50	78	0	78	
Argentina	17.8	24	41.8	0	0	0	17.8	24	41.8	
Australia	289	7	296	44	5	49	333	12	345	8
Austria	1.8	0	1.8	0	0	0	1.8	0	1.8	
Bolivia	0	0	0	0	0.5	0.5	0	0.5	0.5	
Brazil	18.2	0	18.2	8.2	0	8.2	26.4	0	26.4	
Canada	167	15	182	392	264	656	559	279	838	20
Centr.Afr.Emp.	8	0	8	8	0	8	16	0	16	
Chile	0	0	0	5.1	0	5.1	5.1	0	5.1	
Denm.(Greenl.)	0	5.8	5.8	0	8.7	8.7	0	14.5	14.5	
Finland	1.3	1.9	3.2	0	0	0	1.3	1.9	3.2	
France	37	14.8	51.8	24.1	20.0	44.1	61.1	34.8	95.9	2
Gabon	20	0	20	5	5	10	25	5	30	
Germany,FR	1.5	0.5	2.0	3	0.5	3.5	4.5	1.0	5.5	
India	29.8	0	29.8	23.7	0	23.7	53.5	0	53.5	
Italy	1.2	0	1.2	1	0	1	2.2	0	2.2	
Japan	7.7	0	7.7	0	0	0	7.7	0	7.7	
Korea(ROK)	0	3	3	0	0	0	0	3	3	
Madagascar	0	0	0	2	2	2	0	2	2	
Mexico	4.7	0	4.7	2.4	0	2.4	7.1	0	7.1	
Niger	160	0	160	53	0	53	213	0	213	5
Philippines	0.3	0	0.3	0	0	0	0.3	0	0.3	
Portugal	6.8	1.5	8.3	0.9	0	0.9	7.7	1.5	9.2	
Somalia	0	6.2	6.2	0	3.4	3.4	0	9.6	9.6	
South Afr.	306	42	348	34	38	72	340	80	420	10
Spain	6.8	0	6.8	8.5	0	8.5	15.3	0	15.3	
Sweden	1	300	301	3	0	3	4	300	304	
Turkey	4.1	0	4.1	0	0	0	4.1	0	4.1	
U.K.	0	0	0	0	7.4	7.4	0	7.4	7.4	
U.S.A.	523	120	643	838	215	1053	1361	335	1696	40
Yugoslavia	4.5	2.0	6.5	5.0	15.5	20.5	9.5	17.5	27.0	
Zaire	1.8	0	1.8	1.7	0	1.7	3.5	0	3.5	
"World"	1647.3	543.7	2191.	1510.6	585	2095.6	3158	1129	4287	

a. Source: OECD/IAEA, Ref.1.
b. Excludes Eastern Europe, the Soviet Union and China, as well as several other countries for which appropriate data were not available.
c. Recoverable uranium after allowance for ore dilution and mining and milling losses.

These three countries account for 46% of the listed lower-cost reserves but only 23% of the estimated total resources. By contrast, for three countries in which more intensive exploration activities have been carried out--France, Canada, the United States--the reported lower-cost reserves constitute a much smaller fraction of total estimated resources (i.e. France - 39%, Canada - 20%, the U.S. - 31%). These three countries account for 44% of the listed lower-cost reserves and 61% of the estimated total resources. It would appear that the more intensive exploration activities, which should in principle have disclosed a larger proportion of these nations' uranium resources, have also provided a more comprehensive basis for estimating additional uranium resources not yet discovered or not yet sufficiently defined to be counted as reserves.

3. The United States Department of Energy in its National Uranium Resources Evaluation (NURE) Program defines four classes of uranium resources corresponding to different degrees of assurance that the estimated quantities of uranium actually exist. These classes are called Reserves and Potential Additional Resources: Probable, Possible and Speculative. U.S. DOE and OECD identify the first two of these (Reserves and Probable Potential Resources) with the two OECD assurance categories, Reasonably Assured and Estimated Additional Resources. Estimated resources in the Possible and Speculative categories are not included in the OECD/IAEA tabulations*. However, these categories should not be dismissed as idle guesses, as they are inferences by experienced uranium geologists based on plausible, if indirect, geological evidence. "Possible Potential Resources" refers to unidentified deposits in known productive formations in productive provinces, while "Speculative

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*The Uranium Resources Group of the Committee on Nuclear and Alternative Energy Sources (CONEAS) of the National Academy of Sciences, in their review of U.S. uranium resources, also accepted NURE estimates in the two categories Reserves and Probable Potential Resources, but did not include the Possible and Speculative categories.

Potential Resources" refers to uranium that may occur in previously unproductive formations or provinces believed to be favorable for the occurrence of uranium. In the NURE estimates for U.S. uranium resources at forward costs up to \$30/lb U_3O_8 (\$80/kg U), the distribution among categories of assurance is approximately as follows [1]:

A.	Proven reserves	0.52 million tons
B.	Probable additional resources	0.84 " "
C.	Possible	0.86 " "
D.	Speculative	0.37 " "
	TOTAL	2.6 million tons

Thus, nearly as much uranium is listed in categories C and D as in A and B. Only one-fifth of this total is considered proven reserves. In Table 1b, by contrast, notwithstanding a very large disparity between the U.S. and most of the other countries listed with respect to the intensity of exploration activities, the proven reserves up to \$80/kg constitute 52% of the total estimated resources in this cost category (63% for the listed countries excluding the U.S., and 78% for the listed countries excluding the U.S. and Canada).

While the degree of assurance associated with the U.S. categories C and D ("Possible" and "Speculative") is certainly much less than with categories A and B, it seems quite clear that the ratio of total estimated resources to lower-cost reserves* is very conservatively stated, even before allowing for the above-mentioned disparity in exploration efforts.

4. THE UNITED STATES AS A MODEL.

We referred above to a very large disparity in the magnitude and intensity of uranium exploration activities between the United States and most other countries. While it is not possible

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*$\frac{\Sigma AB}{A_I} = \frac{4287}{1647} = 2.6.$

to document this statement precisely, the data presented by the several countries listed in Table 1b and given in the OECD/IAEA report [1], even though fragmentary, provide a clear demonstration of this disparity. Table 2 lists cumulative exploration expenditures and cumulative drilling, through the year 1977. In some cases the figures are presented just as they appear in Reference 1, while in others an attempt has been made to allow for missing data by plausible interpolation or extropolation. The data are also presented on a relative scale, normalized in each case to unity for the United States as the nation in which by far the largest exploration activities have taken place.* While the numbers in Table 2 are certainly not equally reliable (many of the entries in Table 1b may be incomplete, appreciably in error or subject to misinterpretation), it is nevertheless clear (and in fact "well known") that a major fraction of all the uranium activities thus far have taken place in the United States, at a cumulative cost of nearly $1 billion. The cumulative cost of survey and exploration activities in all countries listed in Reference 1, through 1977, appears to be about $2 billion (∿ $1.86 billion), of which a little more than half (∿ 52%) appears to have been spent in the United States. Similarly, from the data in Reference 1, one can account for about 92,000 km of drilling in the listed countries through 1977, of which about 82,500 km (i.e. ∿ 90%) has taken place in the United States.†

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*In South Africa, a major uranium-producing nation, exploration and production have mainly been in conjunction with the same activities for gold, and cannot be separately attributed to uranium. Thus, the data for South Africa are not comparable to those for other countries.

†The percentage is ∿80 - 90%, unless unreported drilling elsewhere (e.g. Canada ?) is really substantial compared to 80,000 km. It would appear that current annual drilling for uranium in the United States ($\gtrsim$ 12,000 - 15,000 km per year) is comparable to the cumulative amount of drilling in all the other listed countries combined since the beginning.

Table 2. Magnitude of Exploration Efforts[1]

Country	Exploration Effort[2] Expense[3] 10^6\$	Drilling[4] 10^3m	Relative Effort Expense	Drilling
United States	970	82500	1.0	1.0
Canada	(≈250?)[5]	n.a.	≈0.25	-
France	160	5151	0.16	0.06
Australia	~100	~1100	~0.1	0.013
Brazil	84	n.a.	0.09	-
India	59	306	0.06	0.004
Argentina	n.a.	200		0.002
Spain	44	638	0.05	0.008
Niger	>34	n.a.	0.04	
Iran	>30	n.a.	0.03	
Centr.Afr.Emp.	20	55	0.02	0.001
Sweden	14	60	0.01	0.001
Japan	14	343	0.01	0.004
Germany,FR	~13	205	0.01	0.002
Mexico	~10	723	0.01	0.009
Turkey	9	146	0.01	0.002
Portugal	7	435	0.01	0.005

[1]Source: OECD/IAEA report (Ref.1)

[2]Within the country, by whatever parties

[3]Estimated from data in Table 1b of Ref.1, through 1977

[4]From individual national reports in Ref.1

[5]Rough estimate from very sketchy information

It further appears that surface drilling, which is necessary for converting estimated resources into reserves, represents a larger proportion of the effort in the United States than elsewhere. This seems reasonable enough, since the drilling must be preceded by general surveys and should be a larger proportion of a large program than of a small one. It is also possible, of course, that there are simply significant inconsistencies in the available data. (The report for the Central African Empire, for example, shows relatively little drilling compared to the reported expense.)

Table 3 shows the "intensity" of these exploration efforts, relative to the areas of the respective countries. The areas of the countries are used as a rough measure of concentration of effort, notwithstanding the obvious fact that geological provinces do not conform to national boundaries. Despite the large area of the United States, much of which has not been considered favorable for uranium occurrences of high quality, the magnitude of expenditures and of total drilling effort per unit area (averaged over the whole country) is second only to that of France. In both countries, of course, these activities have been concentrated in a relatively small fraction of the total area of the country.

While the magnitude of exploration activities in the United States has been large, the rewards, relative to the effort expended, are not exceptional. In Tables 4 and 5, we compare success rates, in reserves established per unit of expense and per unit of drilling. These are cumulative averages, not incremental finding rates, and one of course expects a mature program of exploration and development to experience declining discovery rates, other things being equal.* For this reason and because of probable omissions and inconsistencies in the

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*It should be noted that incremental finding rates in the United States, though lower than in the 1950s and 1960s, have only decreased by a factor of 2 or 3.

Table 3. Intensity of Exploration Efforts[1]

Country	Area $10^6 km^2$	Exploration Intensity Expense $/km^2	Drilling m/km^2	Relative Intensity Expense	Drilling
France	0.55	290	9.4	2.8	1.07
U.S.A.	9.4	103	8.8	1.0	1.0
Spain	0.51	86	1.25	0.84	0.14
Portugal	0.09	78	4.8	0.75	0.55
Germany,FR	0.25	52	0.82	0.50	0.09
Japan	0.37	37	0.92	0.36	0.11
Centr.Afr.Emp.	0.62	>32	0.089	>0.31	0.01
Sweden	0.45	31	0.13	0.30	0.015
Niger	1.2	28	-	0.27	-
Canada	10.0	≈25	-	≈0.24	-
India	3.3	18	0.09	0.17	0.01
Iran	1.6	>18	-	0.17	-
Australia	7.7	13	0.14	0.13	0.16
Turkey	0.78	12	0.19	0.11	0.02
Brazil	8.5	10	-	0.10	-
Mexico	2.0	5	0.36	0.05	0.04
Argentina	2.8	-	0.07	-	0.008

[1]Based on data in Table 2.

Table 4. Uranium Resources vs Exploration Effort[1]

	Estimated Resource A_I	Σ_{AB}		Effort Drill Holes	Expend	Success Reserves, A_I		Relative Success	
	10^3te	10^3te	%	10^3m	$10^6$$	kg/m	kg/$	Drilling	Expense
U.S.	523	1696	40	82500	970	6.3	0.54	1.0	1.0
Canada	167	838	19	n.a.	≈250		0.67		1.2
S.Africa	306	420	10			(2)	(2)		
Australia	289	345	8	~100	~100	260	2.9	40	5.4
Sweden	1	304[3]	7	60	14				
Niger	160	213	5	n.a.	34				<8.7
France	37	96	2	5151	160	7.2	0.23	1.1	0.43
Algeria	28	78	1.8	n.a.	n.a.				
India	30	54	1.2	306	59	98	0.52	16	0.96
Argentina	18	42	1.0	200	n.a.	90		14	
Brazil	18	26	0.6	n.a.	84		0.21		0.40
Centr.Afr.Emp.	8	16	0.4	55	20	145	0.4	23	0.7
Spain	6.8	15.3	0.4	638	44	10.7	0.15	1.7	0.29
Portugal	6.8	9.2	0.2	435	7	15.6	1.0	2.5	<1.8
Japan	7.7	7.7	0.2	343	13.6	22	0.57	3.5	1.1
Mexico	4.7	7.1	0.2	723	10	6.5	0.47	1.0	0.87
Turkey	4.1	4.1	0.1	146	9.2	28	0.45	4.4	0.83

[1] Source: OECD/IAEA (Ref.1)

[2] Data for South Africa not comparable (see footnote, p.9)

[3] Swedish black alum shales, placed by OECD in the higher-cost reserves.

Table 5. Uranium Finding Rates[1]

	Drill Holes 10^3m	Reserves <$80/kg 10^3tonnes	Finding Rate[2] kg/m
Australia	~1100	289	260
Centr.Afr.Emp.	55	8	145
India	306	29.8	98
Argentina	200	17.8	89
Finland	25	1.3	52
Philippines	8.2	0.3	37
Turkey	146	4.1	28
Japan	343	7.7	22
Italy	74.3	1.2	16.2
Portugal	435	6.8	15.6
Spain	638	6.8	10.7
Germany, FR	205	1.5	7.3
France	5151	37	7.2
Mexico	723	4.7	6.5
U.S.A.	82,500	523	6.3

[1]Source: Data taken from OECD/IAEA report (Ref.1)

[2]Cumulative average finding rate, not incremental.
"Reserves" ≡ Reasonably Assured Resources (up to $80/kgU).

data, the numbers in Tables 4 and 5 presumably cannot be interpreted very precisely. Nevertheless, it appears from the data in the OECD/IAEA report (largely reproduced in Tables 1 and 2) that the United States, having incurred roughly 50% of the exploration expense among the reported countries and having drilled roughly 80 - 90% of the total depth of drill holes, is able to report about 32% of the lower-cost reserves (category A_I) and about 40% of the total estimated resources.

The principal conclusion, we think, is that the United States is probably not uniquely endowed with uranium resources, but rather can serve as a useful model for anticipating, on the average, the results of future exploration efforts in other, sufficiently large regions of the world, and in particular for the world as a whole.

5. ESTIMATION OF WORLD URANIUM RESOURCES.

Others have suggested that the success of uranium exploration efforts in the United States could serve as a model for estimating world uranium resources. A. Alexandrov and N. Ponomarev-Stepnoy [4,5] proposed extrapolating U.S. resource estimates to the world as a whole in proportion to the respective areas, and A.M. Belostotsky [6] applied this procedure using the resource estimated given in the previous (1975) edition of the OECD/IAEA report [7]. On the basis of 454×10^3 t uranium reserves and 812×10^3 t estimated additional resources (a total of 1266×10^3 t), Belostotsky estimated world uranium resources to be 17.5×10^6 tons, excluding Antarctica and the continental shelves. On the same basis, using the more recent data for the U.S. from Reference 1 (reproduced in Table 1b), i.e. 1696×10^3 t U, we arrive at an estimate of 23×10^6 tons U for the world as a whole.

Commenting on the validity of his estimate, Belostotsky stated [6]:

> "Surely there can be no final agreement as to whether this figure is an upper or lower estimation, but

there are some good reasons to consider it a lower estimation:

1. With regard to the world uranium resource figure, the U.S. basis is taken at random and has no peculiarities. Rather it seems that uranium resources are rather uniformly spread throughout the world;

2. We took only those U.S. resources which have already been discovered and, as mentioned, there are good prospects for further discoveries;

3. There is a good chance that the upper cost limit for available uranium resources will probably rise, because the limit for conventional resources is also rising.

Thus, we feel that a value of 17.5×10^6 t of U at present-day costs is not excessively optimistic, though it is five times higher than that given by the IAEA in its latest *Report on Uranium Resources*."

In support of Belostotsky's second reason, 2., we note here the comment, already given in Section 3 of this paper, that consideration of the "Possible" and "Speculative" categories, which are included in U.S. DOE estimates for the United States, but not included in the above 1696×10^3 tons, would nearly double the U.S. resource figure used as a basis for estimating world uranium resources, and would raise the estimate of world uranium resources to nearly 50 million tons.

6. APPLICATION TO IIASA REGIONS.

In the IIASA Energy Systems Program, prospects for economic development and for future energy demand and supply are considered separately for seven major regions of the globe, defined not only in terms of geographical proximity, but also in terms of similarity of economic development and possession of indigenous energy resources.

These regions are as follows:

I	North America (United States, Canada)
II	Eastern Europe and the Soviet Union
III	Western Europe, Japan, Australia, New Zealand, South Africa
IV	Latin America (including Mexico)
V	Africa (excluding Algeria, Libya, South Africa), South Asia, Southeast Asia and the Pacific
VI	Middle East, Algeria, Libya
VII	China, North Korea, Mongolia, Vietnam.

Clearly the procedure of extropolating from U.S. resources cannot be applied to arbitrarily selected, small areas. However, these seven regions are sufficiently large and geologically diverse, we believe, to justify application of this procedure.

In Table 6, we list uranium resources from Table 1b, aggregated according to the above regions, with the principal contributors to regional totals separately identified. In Table 7, we list regional areas and resource estimates adjusted according to the assumption used above for the world as a whole, i.e. that equal resources may be attributed to equal areas, using the U.S. as a basis. In discussing the relative success of exploration activities (Section 3), we emphasized the lower-cost reserves (Reasonably Assured Resources below \$80/kg U). Here, however, we make use of the observation (Section 3) that the remaining resource categories appear to have received less attention in the resource evaluations of most countries. On this basis, we use the total resource estimate given for the U.S. in Table 1b (1696×10^3 tons). However, as noted above, we still exclude the "Possible" and "Speculative" categories reported by the U.S. DOE. For this reason, as well as for others cited above, we believe these numbers are more likely to be low than to be high estimates of regional uranium resources.

Table 6. "World" Uranium Resources[a] (10^3MTU)

Region	Selected Countries	A=Reason.Assured			B=Est.Additional			A+B="Total"		
		I <$80/ kg	II $80-130	Σ_A <$130/ kg	I <$80/ kg	II $80-130	Σ_B <$130/ kg	I <$80/ kg	II $80-130	Σ_{AB} <$130/ kg
I	United States	523	120	643	838	215	1053	1361	335	1696
	Canada	167	15	182	392	264	656	559	279	838
	Region total	690	135	825	1230	479	1709	1920	614	2534
II	(not listed)									
III	Australia	289	7	296	44	5	49	333	12	345
	South Africa	306	42	348	34	38	72	340	80	420
	Other	74	326	400	46	52	98	120	378	498
	Region total	669	375	1044	124	95	219	793	470	1263
IV	Argentina	18	24	42	-	-	-	18	24	42
	Brazil	18	-	18	8	-	8	26	-	26
	Other	5	-	5	8	-	8	13	-	13
	Region total	41	24	65	16	-	16	57	24	81
V	Niger	160	-	160	53	-	53	213	-	213
	India	30	-	30	24	-	24	54	-	54
	Other	30	9	39	14	11	25	44	20	64
	Region total	220	9	229	91	11	102	311	20	331
VI	Algeria	28	-	28	50	-	50	78	-	78
	Other	-	-	-	-	-	-	-	-	-
	Region total	28	-	28	50	-	50	78	-	78
VII	(not listed)									
I-VII	"World" total[b]	1647	544	2191	1511	585	2096	3159	1128	4287

[a] Source: OECD/IAEA (Ref.1). Resources listed in 10^3 tonnes of Uranium.

[b] Excludes Regions II, VII, and a number of countries in the other regions for which data are not available.

Table 7. Adjusted Uranium Resource Estimates

	Area $(10^6 km^2)$ (1)	(2)	(3)	(4) (%)	Uranium Resource (10^3 tonnes) OECD Σ_{AB}	Adjusted Σ_{AB} Excl. II, VII	Incl. II, VII	(6) (%)
I	19	0	19	13	2534	3420	3420	100
II	0	23	23	15	-	-	4140	0
III	15.4	0.6	16	11	1263	2880	2880	95
IV	15.1	4.9	20	13	81	3600	3600	75
V	9.3	21.5	31	20	331	5580	5580	30
VI	2.4	6.9	9	6	78	1620	1620	27
VII	0	11.2	11	7	-	-	1980	0
I-VII	61	68	129	85	4287	17100	23220	47
(5)	0	22	22	15	-		(3960)	0
World	61	90	151	100	4287		(27200)	40

(1) Countries listed in OECD/IAEA report (Ref.1)

(2) Countries not listed

(3) Total area of region ((1) + (2))

(4) Region area as percentage of world area

(5) Regions not included elsewhere - Antarctica $(16 \cdot 10^6 km^2)$, other (including perhaps occasional omissions from defined regions) $(6 \cdot 10^6 km^2)$.

(6) Percentage of the regional area included in countries listed in the OECD/IAEA report.

7. SUMMARY.

The OECD Nuclear Energy Agency and the International Atomic Energy Agency, making use of reports submitted by some 50 countries, have estimated world uranium resources to be approximately 4.3 million tons recoverable at forward costs up to $130/kg. This estimate is clearly much too low for analysis of long-range global energy options because it covers less than half the earth's land area, it is restricted to ore grades of essentially current economic interest and it is based in most cases on very limited amounts of exploration. We have presented a qualitative justification for extrapolating from a relatively well-explored area, the United States, to the world as a whole and to seven major regions of the globe. The resulting estimate for commercially useable world uranium resources is 23 million tonnes, excluding Antartica. Pending the outcome of exploration activities far greater than those undertaken so far, we cannot of course know that this much uranium will actually be available world-wide. We believe, however, that this estimate is probably conservative as a guide for long-term energy analysis in a global context.

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