ENERGY

Toward a Bargain of Confidence

Edited by IAN SMART

Edited by Ian Smart

WORLD NUCLEAR ENERGY

(Toward a Bargain of Confidence)

THE JOHNS HOPKINS UNIVERSITY PRESS
Baltimore and London

Copyright © 1982 by The Royal Institute of International Affairs All rights reserved Printed in the United States of America

The Johns Hopkins University Press, Baltimore, Maryland 21218 The Johns Hopkins Press Ltd., London

Earlier versions of chapters two through ten were published separately, copyright 1978, 1979, 1980 by the International Consultative Group on Nuclear Energy.

Illustrations by George Hartfield

Library of Congress Cataloging in Publication Data Main entry under title:

World nuclear energy.

Includes index.

1. Atomic energy industries — Addresses, essays, lectures. 2. Nuclear nonproliferation — Addresses, essays, lectures. I. Smart, Ian.

HD9698.A2W59 333.79'24 82-179

ISBN 0-8018-2652-7 AACR2

World Nuclear Energy

This book has been prepared under the auspices of The Royal Institute of International Affairs.

Contents

List of Figures vii List of Tables ix

1. Introduction

Ian Smart 1

2. Peaceful Nuclear Relations: A Study of the Creation and the Erosion of Confidence

Bertrand Goldschmidt and Myron B. Kratzer 19

 Nuclear Energy and International Cooperation: A Third World Perception of the Erosion of Confidence Munit Ahmad Khan 49

4. International Safeguards 1979

David Fischer 69

- 5. Nuclear Non-Proliferation: Failures and Prospects

 Ryukichi Imai and Robert Press 91
- 6. International Custody of Plutonium Stocks: A First Step toward an International Regime for Sensitive Nuclear Energy Activities

 Russell W. Fox and Mason Willrich 111
- 7. Nuclear Power Plant Lead Times Richard K. Lester 123
- 8. The Viability of the Civil Nuclear Industry

 Mans Lönnroth and William Walker 148
- 9. World Nuclear Energy Paths

 Thomas J. Connolly, Ulf Hansen, Wolfgang Jaek, and
 Karl-Heinz Beckurts 216

vi CONTENTS

10. Report of the International Consultative Group on Nuclear Energy 345

Glossary and Abbreviations 359
Authors 381
International Consultative Group on Nuclear Energy 383
Index 385

List of Figures

7.1 Reactor Lead-time Components 127

United States, and Canada

Plants under and over 800 MW

131

Plants

vii

9.1	Future World Energy Demand: WEC L4 Scenario 230
9.2	Primary Energy Demand in the World and Main Regions:
	WEC L4 Scenario 231
9.3	Nuclear Generating Capacity Projections 241
9.4	Number of Countries Operating Nuclear Power Plants: KFA
	Jülich Reference Scenario 242
9.5	Distribution of Nuclear Generating Capacity Outside Europe in
	2000, 2020: KFA Jülich Reference Scenario 243
9.6	Distribution of Nuclear Generating Capacity in Europe in 2000,
	2020: KFA Jülich Reference Scenario 244
9.7	Fast Breeder Path: Schedule of Plant Orders Required 256
9.8	Fast Breeder Paths: Natural Uranium Savings Compared with
	the Reference Once-through Path 266
9.9	Natural Uranium: Production and Prices, 1950-79 267
9.10	Natural Uranium: Distribution in WOCA of Reasonably
	Assured and Estimated Additional Resources 268
9.11	Natural Uranium: Known and Unknown United States
	Resources at up to \$50/lbU ₃ O ₈ 270

7.2 Major Regulatory Milestones for Japan, West Germany, the

7.5 Average Construction Times for United States Nuclear Power

7.3 Average Preconstruction Lead Times for Nuclear Power

7.4 Construction Lead Times for Nuclear Power Plants

8.1 Functional Breakdown of the Nuclear Industry

129

139

153

viii LIST OF FIGURES

9.12	Natural Uranium: Annual Production Requirements at the
	Mine 273
9.13	Enrichment: Annual Separative Work Requirements at the
	Enrichment Plant 273
9.14	Natural Uranium: Cumulative Requirements, Levels
	I-III 276
9.15	Natural Uranium: Cumulative Mine Production for Different
	Scenarios 277
9.16	Natural Uranium: Cumulative Reserves Required for Mine
	Openings for Different Scenarios 277
9.17	Natural Uranium: Cumulative Commitments Implied by
	Reactor Orders for Different Scenarios 278
9.18	Natural Uranium: Cumulative Requirements by Region in 2000,
	2020 279
9.19	Extended Nuclear Generating Capacity Projections to
	2070 281
9.20	Extended Uranium Requirements Projections to 2070 281
9.21	Natural Uranium: Model for Long-run Price Formation 283
9.22	Fuel Fabrication by Reactor Type: Once-through Path 287
9.23	Fuel Fabrication by Reactor Type: Fast Breeder Paths 288
9.24	Spent Fuel: Accumulation of Fissile Plutonium by Age
	Group 291
9.25	Spent Fuel: Accumulation of Converter Reactor Fuel 292
9.26	Spent Fuel: Accumulation by Region in 2000, 2020 294
9.27	Radioactive Waste: Cumulative Volume for Disposal 295
9.28	Effect of Inflation on Electricity Generating Cost in LWR and
	Coal-fired Plants 298
9.A.1	Model Treatment of a Five-Unit Capacity Increment in the
	Period 1976–80 321
9.A.2	Calculation of Net Plutonium Inputs and Outputs for the

Canadian FBR Program 324

List of Tables

J.1	boolomically recoverable room rate recodings, 1777
4.1	Non-Nuclear-Weapon States Party to the NPT That by
	31 August 1979 Had Concluded the NPT Safeguards
	Agreement with the IAEA Required by Article III of the
	Treaty 80

3.1 Economically Recoverable Fossil Fuel Resources 1977

- 4.2 Non-Nuclear-Weapon States Party to the NPT That by 31 August 1979 Had Not Concluded the NPT Safeguards Agreement with the IAEA Required by Article III of the Treaty 81
- 4.3 Non-parties to the NPT on 31 August 1979 82
- 7.1 Estimated "Total Planning" Lead Times in Current Conditions for Nuclear Power Plant Projects 134
- 7.2 Factors Affecting Nuclear Plant Lead Times 136
- 7.3 Average Construction Time 138
- 7.4 Materials and Labor Required for Nuclear Power Plant Construction in the United States per Unit of Generating Capacity 140
- 8.1 Patterns of Ownership in the Nuclear and Electric Utility Industries 156
- 8.2 Principal Thermal Reactor Suppliers by Country 158
- 8.3 Reactor Manufacturing Capacity and Ordering Rates in Noncommunist Countries 164
- 8.4 Average Reactor Ordering Rates by Vendor Country, 1970-79 166
- 8.5 Environment for United States Utility Industry 169
- 8.6 Distribution of Authority over Electric Utility Industries 170

X LIST OF TABLES

	Countries, 1980–89 191
8.8	Reactor Units Ordered from and Completed or Due for
	Completion by Major Manufacturers, 1951-95 206
	•
9.1	Projected Distribution of Nuclear Generating Capacity 218
9.2	Natural Uranium Consumption and Spent Fuel Arisings 219
9.3	Energy Projections for WOCA to 2000 228
9.4	Energy Projections for OECD to 2020 229
9.5	World Primary Energy Demand by Fuel Type:
	WEC L4 Scenario 229
9.6	World Fuel Supply Status 232
9.7	Regional Electricity Growth Rates: WEC L4 Scenario 235
9.8	Regional Projections of Nuclear Electricity Production 237
9.9	Country Projections of Nuclear Generating Capacity:
	KFA Jülich Reference Scenario 238
9.10	Installed Nuclear Generating Capacity: KFA Jülich Reference
	Scenario 240
9.11	World Nuclear Generating Capacity Expansion: KFA Jülich
	Reference Scenario 245
9.12	Once-through Path: Installed Nuclear Generating Capacity by
	Reactor Type 247
9.13	Once-through Path: World Annual Flows of Materials and
	Services at Reactors 249
9.14	Once-through Path: World Cumulative Flows of Materials at
	Reactors 250
9.15	Once-through Path: Effect of Postulated Evolutionary
	Improvement on Natural Uranium Demand at Reactors 251
9.16	Fast Breeder Path: FBR Deployment and Capacity 254
9.17	Fast Breeder Path: Converter Reactor Fuel Reprocessing
	Throughput Required 255
9.18	Fast Breeder Path: World Annual Flows of Materials and
	Services at Reactors 258
9.19	Fast Breeder Path: World Cumulative Flows of Materials at
	Reactors 258
9.20	Fast Breeder Path: World Fuel Cycle Balance 259
9.21	Fast Breeder/Plutonium Recycle Path: Converter Reactor Fuel
	Reprocessing Throughput Required 262
9.22	Fast Breeder/Plutonium Recycle Path: World Annual Flows of
	Materials and Services at Reactors 263
9.23	Fast Breeder/Plutonium Recycle Path: World Cumulative
	Flows of Materials at Reactors 264

8.7 Estimated Average Reactor Ordering Rates in Noncommunist

9.24	Fast Breeder/Plutonium Recycle Path: World Fuel Cycle
	Balance 265
9.25	Natural Uranium: Estimates of Total World Resources at up to \$50/lbU ₃ O ₈ 271
9.26	Natural Uranium: Annual Production at the Mine for Different
	Scenarios 272
9.27	Natural Uranium: Cumulative Production at the Mine for
	Different Scenarios 272
9.28	Natural Uranium: Cumulative Reserves Required for Mine
	Openings 275
9.29	Natural Uranium: Cumulative Commitments Implied by
	Reactor Orders 276
9.30	Natural Uranium: Regional Estimates of Cumulative
	Consumption and Resource Potential 280
9.31	Natural Uranium: Reference Price Projections to 2020 284
9.32	Enrichment: U235 Extraction and Natural Uranium
	Requirements 285
9.33	Enrichment: Separative Work/Natural Uranium Ratio 285
9.34	Spent Fuel: Distribution by Quantity and Age 290
9.35	Radioactive Waste: Cumulative Quantities for Disposal 296
9.36	Radioactive Waste: Distribution from Reprocessing 297
9.37	Present Worth of Uranium at \$130/kgU over Thirty
	Years 299
9.38	Costs of Fresh UOX and MOX Fuel for LWRs 301
9.A .1	Once-through Cycle Mass Flows over Thirty Years 315
9.A.2	
9.A.3	Lifetime Reactor Requirements over Thirty Years 320
9.A.4	Canada: Fast Breeder Path 326
9.A.5	France: Fast Breeder Path 327
9.A.6	France: Fast Breeder/Plutonium Recycle Path 328
9.A.7	West Germany: Fast Breeder Path 329
9.A.8	West Germany: Fast Breeder/Plutonium Recycle Path 330
9.A.9	Japan: Fast Breeder Path 331
9.A.10	Japan: Fast Breeder/Plutonium Recycle Path 332
9.A.11	Britain: Fast Breeder Path 333
9.A.12	Britain: Fast Breeder/Plutonium Recycle Path 334
9.A.13	United States: Fast Breeder Path 335
9.A.14	United States: Fast Breeder/Plutonium Recycle Path 336
9.A.15	Soviet Union: Fast Breeder Path 337
9.A.16	Soviet Union: Fast Breeder/Plutonium Recycle Path 338
9.A.17	Brazil, China, East Germany, Italy, Spain: Fast Breeder
	Path 339

xii LIST OF TABLES

9.A.18	Brazil, China, East Germany, Italy, Spain: Fast
	Breeder/Plutonium Recycle Path 340
9.A.19	Czechoslovakia, Poland, Sweden: Fast Breeder Path 341
9.A.20	Czechoslovakia, Poland, Sweden: Fast Breeder/Plutonium
	Recycle Path 342
9.A.21	India: Fast Breeder Path 343
9.A.22	Rest of the World (Non-FBR Countries) 344

1

Introduction

Ian Smart

An introduction to this somewhat unusual book has to explain not only what the papers in it contain but also how and why they came to be written, for this particular collection of papers about international nuclear policy issues cannot be fully understood outside the context of its origin.

No one has ever doubted the technical difficulty of exploiting nuclear energy. No one has ever been unaware of the challenge its use presents to those concerned with policy at the local or national level: to men and women in government, but also to ordinary citizens. By 1976, however, some of us who had been involved in one aspect or another of those issues found ourselves increasingly worried also about what we saw as a growing danger of international friction over the ways nuclear energy was being developed for civil use, and especially over the alleged relationship between civil nuclear power and nuclear weapons.

The Non-Proliferation Treaty (NPT), which came into force in 1970, had suggested to many that governments in the West, the East, and the Third World were on the way to establishing an agreed framework of effective rules for separating the atoms of peace from the atoms of war. It seemed that the group of only five countries that had already proved their possession of nuclear explosives might, after all, grow no larger, and that civil nuclear cooperation might meanwhile, on that basis, flourish in an atmosphere of international harmony. Sadly, the hope was short-lived. The problems that, in fact, remained in 1970 turned out to be of daunting proportions. They were increasingly complicated, moreover, by the progressive international diffusion of nuclear technology capable of serving either civil or military purposes. Finally, in 1974, the possible implication of failure to solve those problems was forcefully signaled when a sixth country, India, made and exploded a nuclear device.

Faced with a rising tide of evidence pointing to the enormous difficulty of regulating the spread of inherently ambiguous technology and materials,

many governments, in countries at very different levels of nuclear development, began to question the adequacy or acceptability of existing international arrangements. "Supplier" countries in the industrial world, newly alarmed and suspicious about the use to which such technologies or materials might be put, sought, unilaterally or in concert, to reinforce the barriers to their uncontrolled dissemination. "Recipient" countries, not least in the Third World, found much to resent or fear in what they sometimes saw as an unjustifiable attempt to hinder their civil nuclear development. Thus, by 1976, when the issues of nuclear energy use and nuclear export policy emerged prominently in an American presidential election, the relations between countries engaged in nuclear trade or cooperation had already become increasingly fractious, and sometimes embittered.

The first of the conversations that led eventually to the establishment of the International Consultative Group on Nuclear Energy (ICGNE) took place at about that time between Mason Willrich, while he was still professor of law at the University of Virginia, and myself, while I was still director of studies at the Royal Institute of International Affairs. We both felt that the situation that had come about since 1974 entailed two risks of a kind that might not easily be addressed through formal intergovernmental channels. One was the obvious risk of growing political, as well as commercial, friction between nuclear exporters and importers - suppliers and recipients - especially where the division between them coincided with that between the industrial world of the "North" and the Third World of the "South." The other risk was the more general one that, because of the inhibitions that naturally characterize formal communication between governments, and because so many of the issues likely to affect future nuclear power use were sufficiently delicate or speculative to fall foul of those inhibitions, some prospective sources of serious international friction were unlikely to be explored quickly or effectively enough through official channels.

With the latter risk particularly in mind, we were persuaded that it might be helpful if there could be brought together, under nongovernmental auspices, a small group of people experienced in international nuclear relations, including both senior policymakers and independent observers, to address longer-term issues in that field in a less inhibited manner. Since it would necessarily draw upon experts from importing countries, including those in the Third World, as well as on nuclear suppliers, the group might also have some value as a vehicle for the frank discussion of reasons for, and possible responses to, the growing friction between those groups.

Our interest in the idea of such a group grew stronger as international nuclear relations deteriorated further. The adoption of a more restrictive policy on nuclear exports by the United States, first under President Ford and then under President Carter, was matched by tighter regulations on the part of other exporters of uranium or nuclear equipment and services. Importing countries were audibly unhappy about the effects. Moreover, exporting coun-

tries were by no means in complete agreement as to what should or should not be done. When President Carter, in April 1977, gave notice that his administration would seek to revise bilateral cooperation agreements to reflect its own opposition to separating and using plutonium, the critical international reaction was no more than the predictable expression of a wider malaise.

The great majority of governments continued to share a desire to prevent control of nuclear weapons from spreading to additional countries, as they also shared a general interest in securing for the world the peaceful benefits of nuclear power. Palpably, however, nations were increasingly at odds about the appropriate means to those separate ends and about the way they were to be reconciled. There was every reason, in those circumstances, to persist in the attempt to investigate those problems through the informal medium of a new international group of experts. Our plans were therefore pressed to fruition. The Rockefeller Foundation (to which Mason Willrich had moved to direct the International Relations Division) was willing to consider an application for funds, and the Royal Institute of International Affairs (from which I was preparing to depart) agreed in principle to act as the proposed group's cosponsor. The way was thus clear to issue preliminary invitations, in June 1977, to those who might form the ICGNE.

It required no great perspicacity in 1977 to see the need for a larger effort to understand and resolve international discord over nuclear energy development. Certainly the governments concerned were well aware of the costs and risks involved. It came as no surprise, therefore, when the United States government took the lead in launching, from October 1977, a broad intergovernmental assessment of the technical relationship between civil nuclear programs and nuclear weapons proliferation, in what was entitled the International Nuclear Fuel Cycle Evaluation (INFCE). By that time, plans for establishing the ICGNE had of course reached maturity. Clearly, however, the fact that governments had agreed to set up INFCE at about the same time raised a question about the sense of international deficiency that underlay the ICGNE concept.

On reflection, those in New York and London who had been planning the ICGNE enterprise were firm in the view that the proposal had lost none of its force as a result of government plans. Although motives for the two initiatives overlapped, and though some individuals might be involved in both exercises, their expected results were quite different. Three things stood out. First, the ICGNE would be predominantly concerned with political, rather than technical, issues, whereas INFCE was expressly to limit itself to technical assessment. Second, the ICGNE, partly because of its bias toward politics, would have a broader and longer perspective. Third, the ICGNE would be a small group of not more than twenty persons, meeting privately and speaking exclusively in their personal capacities, without any duty to represent states or national policy positions. Their deliberations could therefore expect to be less inhibited than those in a larger and more open government forum.

4 INTRODUCTION

A measure of incidental complementarity between the roles of INFCE and the ICGNE could not be excluded, but no conflict was seen. Nevertheless, it was prudent to submit that view to the judgment of those who would actually constitute the ICGNE. The formal invitations spoke, therefore, of an initial meeting "to evaluate our tentative plans for the Group's activity, before committing ourselves and those we are inviting to a longer programme of meetings." In the event, the unanimous opinion was that the ICGNE should be constituted for at least two years. On that basis, the Rockefeller Foundation agreed to provide the additional funds needed and to act formally, with the Royal Institute of International Affairs, as the group's sponsor.

The group invited to meet for the first time in London at the end of October 1977 had a broad but not unlimited purpose and a diverse but not unconstrained membership. The cosponsors had agreed at an early stage that, if useful results were to be obtained in a reasonable time, some limit would have to be placed on the ICGNE's agenda. The most important limit was that the group should not be expected to debate the intrinsic virtues and vices of nuclear power. Given that the aim was to focus on questions of international cooperation and conflict, it should rather assume that attempts to exploit nuclear power would occur in a growing number of countries and should concentrate on how such an expansion might be made internationally tolerable and harmonious. From that decision there flowed conclusions not only about the agenda but also about the group's composition. It became unnecessary, for instance, to include a complete spectrum of opinion on the inherent value of nuclear fission as a means of supplying energy. Arguments for and against nuclear power, in terms of cost, safety, environmental impact, and social effect, were familiar ground, and no one involved in the ICGNE was insensitive to their significance or to the sometimes delicate balance between them. But it was never intended that the ICGNE should conduct, still less resolve, arguments of that kind. Nor, therefore, was it necessary that its membership should embrace the diverse strands of opinion on those issues.

What was necessary was that the ICGNE's membership should be balanced in at least three other respects, all bearing on the central theme of international nuclear relations. It should include a range of views on the rate at which civil use of nuclear power could realistically be expanded in different parts of the world. It must also include a diversity of interests in civil nuclear activities and the nuclear fuel cycle: the supply and processing of nuclear raw materials, the design and operation of nuclear power plants, the regulation as well as the management of nuclear industries, and above all the conduct of international negotiations on nuclear energy and its control. Finally, it was essential that the ICGNE should include personally authoritative voices from a representative selection of regions and nations, covering suppliers and recipients and developing as well as industrialized states. When that last point was weighed against the earlier conclusion that not more than twenty persons