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PEACEFUL USES OF ATOMIC ENERGY

PROCEEDINGS OF THE
FOURTH INTERNATIONAL CONFERENCE ON
THE PEACEFUL USES OF ATOMIC ENERGY
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AND HELD IN GENEVA, 6 - 16 SEPTEMBER 1971

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UNITED NATIONS, NEW YORK
INTERNATIONAL ATOMIC ENERGY AGENCY, VIENNA
1972

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UN Sales No.: 72.IX.2
IAEA Sales No.: STI/PUB/300/Vol. 2

PEACEFUL USES OF ATOMIC ENERGY
UN, NEW YORK, AND IAEA, VIENNA, 1972

FOREWORD

The Fourth International Conference on the Peaceful Uses of Atomic Energy, held at Geneva from 6 to 16 September 1971 under the Presidency of Glenn T. Seaborg, was jointly sponsored by the United Nations and the International Atomic Energy Agency. The conference sessions were held at the Palais des Nations. During the same period a Governmental Scientific Exhibition on the theme "Atoms for Development" was displayed at the Palais des Expositions in Geneva.

The Proceedings are published in 15 main volumes, fourteen of which contain all the 514 papers presented at the conference. The papers are printed in English, French, Russian or Spanish, and the abstracts in all four languages; the discussions are in English. The fifteenth volume contains a Subject Index, an Author Index (including discussion contributors), a Paper Number Index, a complete Contents List of all volumes, and a List of Delegations. There are three supplementary volumes containing the discussions in French, Russian and Spanish respectively.

The conference, which attracted more than four thousand participants, observers and journalists, was planned to interest not only scientists and technologists but also public officials, economists and planners. It thus had a somewhat broader scope than the conferences of 1955, 1958 and 1964. The main topics were grouped under the following six headings: nuclear power; nuclear fuels and materials; health, safety and legal aspects; isotopes and irradiation; international and administrative aspects; and selected subjects of particular interest to developing countries.

The fourth Geneva Conference proved again to be an exceptional forum enabling those working throughout the world on the peaceful application of atomic energy to exchange the latest information on the discoveries, projects and problems of both developed and developing nations.

SUMMARY OF COMPLETE CONTENTS

CONTENTS OF VOLUME 2

AGENDA ITEM 1.4: TECHNIQUES FOR COSTING NUCLEAR POWER PLANTS AND RECENT COST TRENDS

AGENDA ITEM 2.9: PRACTICAL ASPECTS OF NUCLEAR FUEL MANAGEMENT FOR ELECTRIC POWER UTILITIES

AGENDA ITEM 1.3

Performance of nuclear power plants

Performances des centrales nucléaires

Работа ядерных электростанций

Rendimiento de las centrales nucleares

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UNITED STATES OF AMERICA
A/CONF.49/P/036

OPERATING EXPERIENCE WITH COMMERCIAL CENTRAL-STATION LIGHT-WATER REACTORS IN THE UNITED STATES OF AMERICA

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Abstract–Résumé–Аннотация–Resumen

OPERATING EXPERIENCE WITH COMMERCIAL CENTRAL-STATION LIGHT-WATER REACTORS IN THE UNITED STATES OF AMERICA.

In the USA commercial nuclear power has been a reality for more than a decade. The USAEC has forecast that 150 000 MW of nuclear generating capacity should be installed and operating in the USA by 1980. The nuclear industry feels that this forecast is reasonable. Because the nuclear industry is continuing its rapid growth, this paper examines the operating experience of United States light-water central-station nuclear power plants since 1964. During the accumulation of almost 100 reactor-years of operating experience, operational and component problems have been diverse. The economics and technical difficulties associated with solving startup and breakdown problems are presented. Data on nuclear power plant availability and the effect on total utility-system operations are also presented. During 1969, United States reactor availability varied from 51.5 to 95.4%. The problems experienced in operating the lower efficiency reactors and the solutions to these problems are discussed. Experience with various components, materials, and operational procedures as well as reactor availability during peak demand periods are evaluated and documented. During 1970 and the first part of 1971, several large water reactors in the 800 MW capacity range were brought into operation. Information on operating and startup problems unique to the large reactors is included.

EXPERIENCE ACQUISE DANS L'EXPLOITATION DES CENTRALES DOTEES DE REACTEURS COMMERCIAUX A EAU LEGERE AUX ETATS-UNIS D'AMERIQUE.

La production commerciale d'électricité à l'aide de l'énergie nucléaire est devenue réalité aux Etats-Unis d'Amérique il y a plus de 10 ans. L'USAEC a prédit que la puissance nucléaire installée et en exploitation atteindra 150 000 MW en 1980. L'opinion des experts de l'industrie nucléaire est que cette prédiction est raisonnable. Etant donné la croissance continuelle et rapide de l'industrie nucléaire, le mémoire fait le point de l'expérience acquise aux Etats-Unis depuis 1964 dans l'exploitation des centrales pourvues de réacteurs de puissance à eau légère. Pendant cette période d'exploitation, qui correspond à 100 ans de fonctionnement d'un réacteur, se sont posés de nombreux problèmes de fonctionnement et de structure. Les auteurs décrivent les difficultés d'ordre technique et économique rencontrées pendant le démarrage et les pannes de réacteur. Ils présentent des données sur la disponibilité des centrales nucléaires et son effet sur l'exploitation d'un réseau intégré de puissance. En 1969, la disponibilité des réacteurs américains a varié de 51,1 à 95,4%. Les auteurs discutent l'expérience acquise dans l'exploitation des réacteurs à efficacité réduite et les propositions qui ont été avancées pour résoudre ces problèmes. Ils apportent aussi des évaluations et des données concernant l'expérience obtenue avec les dispositifs, matériaux et techniques opératoires et la disponibilité des réacteurs pendant les périodes de demande maximale. Pendant l'année 1970 et le début de 1971 un certain nombre de réacteurs de grande taille, refroidis à l'eau légère, ayant chacun une capacité d'environ 800 MW, ont été mis en service. Les auteurs mentionnent les problèmes spécifiques de démarrage et d'exploitation des réacteurs à haute puissance.

ОПЫТ ЭКСПЛУАТАЦИИ КОММЕРЧЕСКИХ АТОМНЫХ ЭЛЕКТРОСТАНЦИЙ С ВОДО-ВОДЯНЫМИ РЕАКТОРАМИ В СОЕДИНЕННЫХ ШТАТАХ АМЕРИКИ.

Промышленное использование атомной энергии в США продолжается уже более десяти лет. КАЭ США планирует, что к 1980 году мощность всех атомных электростанций США достигнет 150 000 МВт. Представители атомной промышленности считают, что такой прогноз является вполне обоснованным. Поскольку атомная энергетика продолжает бурно развиваться, в данном докладе будет рассмотрен опыт эксплуатации атомных электростанций с водо-водяными реакторами, накопленный в США, начиная с 1964 года. За время работы реакторов в течение почти 100 реактор-лет был накоплен опыт в области их эксплуатации, в этот период возникали и решались различные эксплуатационные и конструктивные проблемы. Встречались также экономические и технические трудности, связанные с решением проблемы пуска и остановки реакторов. В докладе приведены данные по коэффициентам использования атомных электростанций и по их влиянию на общую эксплуатацию энергосистем. В 1969 году коэффициенты использования для атомных электростанций США колебались от 51,5 до 95,4%. Обсуждаются проблемы, связанные с эксплуатацией реакторов с более низкими к.п.д., а также рассматриваются пути решения этих проблем. Рассмотрен опыт эксплуатации различного реакторного оборудования, использования материалов, применения различных методов управления атомными электростанциями, а также указаны коэффициенты использования атомных электростанций в период максимального потребления электроэнергии. В течение 1970 года и первой половины 1971 года введено в эксплуатацию несколько крупных водо-водяных реакторов мощностью примерно по 800 МВт каждый. В доклад включены некоторые сведения о проблемах эксплуатации и пуска крупных реакторов.

EXPERIENCIA RELATIVA AL FUNCIONAMIENTO DE LAS CENTRALES CON REACTORES COMERCIALES DE AGUA LIGERA EN LOS ESTADOS UNIDOS DE AMERICA.

La electricidad de origen nuclear en escala industrial consituye una realidad en los Estados Unidos de América desde hace más de diez años. La USAEC ha previsto que para 1980 habrá instalada y en servicio en el país una capacidad nuclear de 150 000 MW. La industria nuclear considera esta previsión razonab.:. Dado que la industria nuclear prosigue su rápido desarrollo, en la memoria se examina la experiencia relativa al funcionamiento de las centrales nucleares con reactores de agua ligera en Estados Unidos desde 1964. Durante los casi 100 años-reactor que suma la experiencia acumulada ha habido diversos problemas de funcionamiento y de componentes. Se exponen las dificultades económicas y técnicas relacionadas con la puesta en marcha y las paradas. Se presentan también datos sobre la disponibilidad de las centrales nucleares y los efectos sobre el funcionamiento global de las redes de las compañías. En 1969 la disponibilidad de los reactores en los Estados Unidos osciló entre el 51,5 y el 95,4%. Se examinan los problemas planteados por los reactores de bajo rendimiento y las soluciones halladas. Se expone y valora con apoyo de documentos la experiencia relativa a diversos componentes, materiales y modalidades de funcionamiento así como la disponibilidad de los reactores durante períodos punta. En 1970 y principios de 1971, entraron en servicio varios grandes reactores de agua, con una capacidad del orden de los 800 MW. Se facilita información sobre los problemas de puesta en marcha y funcionamiento propios de los grandes reactores.

1. INTRODUCTION

This paper summarizes nuclear power plant operating experience and nuclear steam system availability for 19 commercial central-station light-water and dual-purpose nuclear power reactors in the United States (Table I). A central-station nuclear power plant is defined as a facility designed and constructed for operation on a utility system. Dual-purpose plants are considered to be nuclear power facilities designed, constructed and operated for more than one primary purpose, e.g., the production of nuclear materials and the generation of electricity, the conducting of research experiments while generating electric power, etc. These commercial reactors have generated about 90 billion kWh of electricity.

To examine the performance for nuclear steam supply systems since 1964, operating and availability data from fossil-fuel units, have been used as a point of comparison in Fig. 1 (a-d). In comparing the steam-system availability for fossil-fuel units with that of nuclear units, the charts indicate that from one year to the next the availability of fossil-fuel steam systems is generally fairly constant, averaging around 80% for units larger than

500 000 kW. By contrast, the nuclear unit steam-system availability can fluctuate widely from one year to the next because of scheduled fuel reloading and occasional plant modifications. Thus nuclear steam systems may have an availability as high as 98% in one year and only 60% the following year. Data on availability of fossil-fuel units and their steam systems were provided by the Tennessee Valley Authority.

Rather than focus on plant operating experience alone, an analysis of nuclear steam supply system availability is really necessary to detect the "non-nuclear" factors which have affected nuclear plant operating statistics. Cooling water intake problems, transformer outages and generator problems cannot be cast as solely nuclear in nature even though they do affect plant availability. Through 1969, commercial nuclear plant operating availability had averaged slightly more than 78%.

In addition to data on plant and nuclear steam supply system availability, information is also presented on certain reactors for performance as part of a total utility system, on technical difficulties associated with startup and operation, and on experience with various reactor components.

2. DRESDEN NUCLEAR POWER STATION: UNITS 1 AND 2

Dresden-1, a 200 000-kW dual-cycle forced circulation boiling-water reactor, has been operated since 1960 by Commonwealth Edison Company of Chicago, Illinois. It was the first full-scale, privately financed nuclear power plant to go into operation in the United States. About half the steam is generated in the reactor by direct boiling and the balance is generated by secondary steam generators. The unit can readily accommodate load changes to meet peaking demands, and can be operated at low loads at night when many of Commonwealth's large coal-fired base load units are already operating at minimum load levels. Average load is approximately 150 000 kW, depending on load requirements.

The reactor's nuclear steam supply system availability from 1963 through 1970 has ranged from 60.1% to 97.2%, with an average of 79.5%. The lower values are primarily due to plant refuelling outages, which take longer because of required surveillance inspections, modifications and piping replacement. For three years out of the last eight, the steam system has experienced no forced outages.

Most plant outages were due to equipment problems such as leaks in valves and piping or in the tubes in the heat exchanger. Of the 82 outages the plant experienced between 1963 through 1970, 41 were forced outages and 41 were scheduled. While most forced outages were caused by various turbine system problems, including oil system, steam piping and condensate system problems, 11 were due to operator or instrument maintenance errors and 4 were the result of malfunctioning of the reactor in-core system instrumentation. In 1967, the unit underwent a major metallurgical inspection which required 1206 h and reduced plant availability to a considerable degree for that year.

One interesting forced outage occurred on 12 November 1965 when a tornado passing north of the station caused the loss of all transmission facilities with a resultant complete load shed from a power level of 200 000 kW. Loss of load resulted in a turbine overspeed trip which closed all steam valves to the turbine. The closing of the steam valves

TABLE I. LIGHT-WATER REACTORS IN THE UNITED STATES

Station	Dresden 1	Dresden 2	Yankee	Indian Point 1	Indian Point 2
Location	Morris, Ill.	Morris, Ill.	Rowe, Mass.	Buchanan, N.Y.	Buchanan, N.Y.
Reactor type	BWR dual cycle	BWR	PWR	PWR, fossil fuel Superheat	PWR
Date critical	15 Oct. 1959	1969-1970	19 Aug. 1960	2 Aug. 1962	
Owner, operator	Commonwealth Edison Co.	Commonwealth Edison Co.	Yankee Atomic Electric Co.	Consolidated Edison Company	Consolidated Edison Company
Reactor Mfgr.	General Electric	General Electric	Westinghouse	Babcock & Wilcox	Westinghouse
Thermal capacity (MW(th))	700	2527	600	615	2758
Electrical capacity, gross (MW(e))	210	849	185	275 (163 + 112)	908
Electrical Capacity, net (MW(e))	200	809	175	255 (151 + 104)	873
Moderator	Water	Water	Water	Water	Water
Coolant	Water	Water	Water	Water	Water
Coolant exit (°C)	286	286	286	266	313.3
Coolant exit (kg/cm^2 abs)	70.3	70.3	140.6	105.5	157.1
Steam gen. exit (°C)	286	286	264	235 (saturated) 538 (superheat)	263.8
Steam gen. exit (kg/cm^2 abs)	70.3	70.3	35.2	31.3 (saturated) 26 (superheat)	50.86
Steam flow (kg/h)	635 025 pri. 544 308 sec.	3 918 182	1 090 909	1 080 000	5 290 800
COSTS Land, structures ($)	6 300 000		8 900 000	45 270 000	19 000 000
Reactor plant ($)	45 000 000	81 000 000	15 800 000	58 459 000	42 000 000
Turbo-gen. & Other plant ($)	Included on above figure		11 900 000	26 210 000	45 000 000
Other[a] ($)			7 000 000	Included in above costs	41 000 000
Total ($)	51 300 000	95 000 000	43 600 000	129 946 000	147 000 000
$/kW	257	117	220	509	168

San Onofre (Unit 1)	Humboldt Bay (Unit 3)	Big Rock Point	Connecticut Yankee Atomic Power Plant	Oyster Creek (Unit 1)	Robert E. Ginna (Unit 1)
San Clemente, Calif.	Eureka, Calif.	Charlevoix, Mich.	Haddam Neck, Conn.	Forked River, N.J.	Ontario, N.Y.
PWR	BWR	BWR	PWR	BWR	PWR
Jun. 1967	16 Feb. 1963	27 Sep. 1962	24 Jul. 1967	3 May 1969	Nov. 1969
Southern Calif. Edison Co. and San Diego Gas & Electric Co.	Pacific Gas & Electric Co.	Consumers Power Company	Connecticut Yankee Atomic Power Co.	Jersey Central Power and Light	Rochester Gas & Electric Co.
Westinghouse	General Electric	General Electric	Westinghouse	General Electric	Westinghouse
1347	240	240	1825	1690	1300
450	65	75	600	580	448
430	63	71.3	575	560	425
Water	Water	Water	Water	Water	Water
Water	Water	Water	Water	Water	Water
314	295	288	304	286	319
146.6	81.9	73.8	140.6	71.3	157.1
263	295	288	260	286	270
48.9		73.8	50.4	71.3	54.9
2 593 636	394 632	274 876	3 500 000	2 834 467	2 500 000
11 581 000	4 200 000	5 000 000	19 000 000	15 951 000	11 666 000
35 815 000	10 300 000	11 000 000	42 000 000	26 763 000	26 990 000
32 667 000	5 300 000	8 000 000	40 000 000	22 880 000	27 004 000
4 872 000	4 400 000	3 000 000		25 807 000	17 515 000
84 935 000	24 200 000	27 000 000	101 000 000	91 409 000	83 175 000
189	370	360	168	163	194

TABLE I (cont.)

Station	Nine Mile Point	Point Beach	Millstone (Unit 1)	N Reactor	Shippingport
Location	Sciba, N.Y.	Two Creeks, Wis.	Waterford, Conn.	Richland, Wash.	Shippingport, Pa.
Reactor type	BWR	PWR	BWR	Graphite	PWR
Date critical	1969	1970	26 Oct, 1970	1963	2 Dec, 1957
Owner, operator	Niagara Mohawk Power Corp.	Wis. Elec. Power Co. & Wis. Mich. Power Co.	Millstone Point Company	AEC - Wash. Public Power Supply Systems	AEC, Duquesne Light Co.
Reactor Mfgr.	General Electric	Westinghouse	General Electric	General Electric	Westinghouse
Thermal capacity (MW(th))	1538	1518	2011	4000	505
Electrical capacity, gross (MW(e))	525	524	682	800	100 (core capacity 150 mWe)
Electrical capacity, net MW(e))	500	497	652	790	90
Moderator	Water	Water	Water	Graphite	Water
Coolant	Water	Water	Water	Water	Water
Coolant exit (°C)	286	317	288	277	296
Coolant exit (kg/cm^2 abs)	70.3	157.1	73.8	105.5	140.0
Steam gen. exit (°C)	286	271		206	252
Steam gen. exit (kg/cm^2 abs)	70.3	52.0		117.8	42.2
Steam flow (kg/h)	2 689 272	3 000 360	3 600 700	5 578 000	888 000
COSTS Land, structures ($)	34 100 000	12 000 000	22 410 000	Not available	14 600 000
Reactor plant ($)	42 100 000	22 280 000	37 225 000	Not available	18 800 000
Turbo-gen. & other plant ($)	33 400 000	26 307 000	32 316 000	85 000 000 (WPPSS)	12 100 000
Other [a] ($)	53 400 000		6 146 000		27 400 000
Total ($)	163 000 000	60 587 000	98 097 000	Not available	72 900 000
($/kW)	310	124	150		1220

[a] Interest, additional indirect construction costs, contingencies, escalation and other related costs.
[b] In the process of being decommissioned.
[c] Includes fuel for 5 years of operation.

Saxton	Elk River [b]	Bonus [b]	La Crosse	Pathfinder [b]
Saxton, Pa.	Elk River, Minn.	Punta Higuera, Puerto Rico	Genoa, Wis.	Sioux Falls, S.C.
PWR	BWR Fossil Fuel Superheated	BWR, Integral Nuclear Superheated	BWR	BWR, Nuclear Superheat
13 Apr. 1962	Nov. 1962	1964	Dec. 1968	24 Mar. 1964
Saxton Nuclear Experimental Corp.	AEC - Rural Coop. Power Association	AEC & Puerto Rico Water Resources Authority	AEC & Dairyland Power Cooperative	Northern States Power Co.
Westinghouse	Allis-Chalmers	Combustion Engineering	Allis-Chalmers	Allis-Chalmers
28	58.2	50	165	200 (157 + 43)
4	23	17.3	55	66
3.25	22	16.3	52	62
Water	Water	Water	Water	Water
Water	Water	Water	Water	Water and steam
259	280	282 (saturated) 482 (superheat)	303	Same as steam
159	65.8	63 (superheat)	90.3	Same as steam
231	263 (saturated) 442 (superheat)	482		254 (saturated) 441 (superheat)
29	49.2 (saturated) 42.2 (superheat)	63		43.2 (saturated) 38.7 (superheat)
36 700	102 000	69 000	1 238 000	280 319
	4 193 295	905 422		3 000 000
	7 674 870	13 000 000	18 000 000	7 600 000
7 000 000 [c]	1 201 842	1 981 827	7 000 000	6 700 000
	440 678	3 180 299		4 000 000
	13 510 685	19 067 000	25 000 000	21 800 000
	587	1909	500	350