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STUDY OF ADVANCED PROFESSIONAL EDUCATIONAL REQUIREMENTS
RELATIVE TO NUCLEAR FUEL CYCLE ENGINEERING
IN INDUSTRY AND GOVERNMENT

QUARTERLY REPORT

FOR THE PERIOD

APRIL 1, 1979 - JUNE 30, 1979

TIM A. JUR

AUGUST, 1979

MASTER

WORK PERFORMED UNDER CONTRACT

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UNIVERSITY OF SOUTH CAROLINA
COLUMBIA, SOUTH CAROLINA 29208

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Appendix A Nuclear Fuel Cycle

Appendix B Metallurgy of Stainless Steels and Nickel-Based Alloys

Appendix C Publication - "Advanced Professional Educational
Requirements of Engineers in the Nuclear
Industry"

) reprint
removed

ABSTRACT

The purpose of this project has been to develop a response to the educational needs of engineers working in the Southeast's nuclear industry. The first phase of the project, now complete, was a study to assess the nature of the educational need. The second phase was intended to implement a program to meet those needs. Due in part to continued reorganization within DOE a proposal for implementation was never acted upon. DOE did however approve application of residual funds from the study phase to a modest initiation of implementation activity. Work is now underway in the development of educational packages in two subject areas: "The Nuclear Fuel Cycle" and "The Metallurgy of Stainless Steel and Nickel-Base Alloys".

1. BRIEF SUMMARY OF THE PROJECT AND ITS OBJECTIVES

The original purpose of this project was to bring about a response to the educational needs of practicing engineers who work in nuclear related areas. From its beginning the project was kept regional in nature and focused on the relatively high concentration of industry and government facilities in the southeastern United States. Since the project concerned practicing engineers, the educational needs addressed have been those at the post-baccalaureate level.

The project began with a study phase which lasted the throughout FY 78 and into December, 1978. This study phase of the project was conducted by a team of faculty from the College of Engineering who personally interviewed engineers and scientists at work in the region's nuclear industry. From these interviews the faculty team was able to piece together a fairly accurate and comprehensive view of the kind of program which these people would like to have made available to them and their colleagues. A list of subject areas was compiled which included many areas unique to the industry and also many areas which would have been identified regardless of which industry had been interviewed. The list is reproduced here in this report as Fig. 1. In general it can be said that the type of program identified included a spectrum of technical know-how not typically covered in the traditional, graduate level engineering curriculum.

The study was completed and a report issued in December, 1978. The faculty, or anyone else who wanted to use the information, now had available a complete list of subject areas including the content, depth and breadth within subject areas. Background information in terms of reference material and learning resources had also been established. The faculty had also developed, in the process, a professional relationship and a rapport with many

individuals from throughout the region's technical community which could do nothing but foster future successful interactions.

In brief the study phase provided the intended basis for implementing educational program of particular usefulness to the region's nuclear community. Prior to the end of the study phase, the College of Engineering requested support for the next phase of activity, that of implementation. A modest program of implementation was proposed, recommending the development of six to ten educational packages from among the subject areas identified in the study. DOE was reorganizing at this time and the request for additional support (made in September, 1978) was not acted upon. However, approval was given in May, 1979 to release monies not expended during the study phase (approximately \$29,000) and apply these to support some initial effort toward implementation. Presumably the program would once again be reviewed late in FY 79 for possible continuing support in FY 80.

2. THE IMPLEMENTATION PLAN

To some extent implementation on a no-cost basis was already underway before the actual approval to spend money in implementation was received from DOE in May, 1979. Many of the faculty who had been working on the project had already begun to build into their graduate courses material which reflected their knowledge of problem areas and educational needs within the nuclear industry. Many of their courses have since been taught or are scheduled to be taught over the College's regionally televised graduate program. Many of the participants in this program come from regional nuclear industry and hence are now benefiting from the added dimensions to parts of the existing program. In addition one new graduate course was approved in "Nuclear Fuel Cycle Engineering" and has been scheduled to be taught the first time in Spring 1980 or Fall 1980 depending upon the rate of development of course materials

and availability of qualified faculty.

Actual implementation along the lines identified in the needs analysis survey, however, was delayed until support for that activity became available. As stated in the previous section, support for initial implementation was arranged with funds left over from the original contract. It was originally intended to have three persons working on the project through the remainder of FY 79. However, due to teaching activities and other assignments, the manpower available to the project was reduced to less than half of that anticipated. It had originally been intended to complete one educational package and parts of at least two others prior to the end of FY 79. However, faced with limited resources in terms of people available to the project, the plan has become one of trying to at least get a good start on two education packages before FY 79 ends.

3. SUMMARY OF QUARTER'S ACTIVITIES

The quarter's activities actually began in early May 1979 when approval was received to use left over Phase I monies on an initial effort to develop educational packages. During this time period two members of the faculty have been working on the project, Dr. Curtis Rhodes and Dr. Tim Jur (as principal investigator). Dr. Rhodes is scheduled to leave the project in early July to take up teaching responsibilities and subsequently to go on sabbatical at Oak Ridge National Laboratories. Dr. Jur is available to the project through September 30, 1979.

The subject areas selected from development were taken from the list shown in Fig. 1 and are as follows:

"Nuclear Fuel Cycle"

"Metallurgy of Stainless Steel and Nickel-Based Alloys".

"ASME Boiler and Pressure Vessel Codes - Failure Modes"

The subject area "Nuclear Fuel Cycle" is expected to be developed into a full three credit hour graduate course and, as previously mentioned, is scheduled to be taught regionally in Spring, 1980 or Fall, 1980. The subject area "Metallurgy of Stainless Steel and Nickel-Based Alloys" is being developed into a video-taped course of from 12-14 tapes to be marketed both regionally and nationwide by the Association for Media-Based Continuing Education for Engineers (AMCEE). The University of South Carolina is a member of the Association. The subject area concerning the boiler and pressure vessel codes has been worked on very little this past quarter and is not reported on here.

a. Nuclear Fuel Cycle (Dr. Curtis Rhodes)

The course description and reference materials relative to this subject area which were published in the study phase report are reproduced here in Appendix A. After critically reviewing the course outline contained therein it has been decided to leave it unaltered as a guide for developing a graduate course here at the University of South Carolina. Some caution, however, should be taken in following this outline. The breadth of course material lends itself to an eventual development of a survey course. A survey course is not what is intended here. Rather it is suggested that the instructor use the outline as a guide in dealing with the course participants and tailor the depth of treatment of any one topic to meet their needs.

A major roadblock to the development of any specialized advance course is a lack of good problem material to use as examples, home assignments and exam questions. For this reason initial activities in course development have been directed toward problem material development. A total of 12 problems in the area of Uranium Enrichment and six in the area of Spent Fuel Reprocessing have been developed thus far and are given in Appendix A. Solutions

are available for the problems on Uranium Enrichment.

Also, in the process of reviewing the course description and developing new problem material, additional reference material has been identified and which is also listed in Appendix A.

b. Metallurgy of Stainless Steel and Nickel-Based Alloys (Dr. Tim Jur)

The course description and reference material relative to this subject area which were published in the study phase report are reproduced in Appendix B. The course description contained therein has been reviewed, revised and expanded and is included in Appendix B along with additional reference material.

As stated previously this course is being developed for presentation as a video taped package consisting of from 12-14 tapes. To supplement these tapes a set of prepared course notes is to be also available, extracted largely from a set of instructor's notes which is now under development. Work on the instructor's notes has been rough going due part to the lack of appropriate reference materials. In general, reference materials available fall one of the following classifications:

1. Manufacturer's product literature specific to individual alloy types.
2. In depth metallurgical references often without regard to applications.
3. Elementary references with an emphasis on applications but little metallurgical reasoning as to why certain selections are made.

In brief there is not a great deal of literature useful to the engineer who does not have an extensive background in metallurgy but who would still like to make intelligent choices of material and their treatment based on fundamental metallurgical reasoning. Lack of such reference materials also requires that more attention be paid to the prepared course notes designed

to supplement the tapes. As of the end of this quarter's activities instructors notes are approximately 25% complete.

Thought has also been given to the nature and design of problems assignments relative to the course. Recognizing that the course is applications oriented, the plan is to develop problem assignments as case studies built around actual experience in the industry. Thus far persons have been identified at the Westinghouse Fuel Fabrication Plant in Columbia, South Carolina and at Oak Ridge National Laboratories who have agreed to help in this effort.

c. Publication Relative to Phase I Activities (Tim Jur and Don Keating)

In addition to work on course development during the semester, a paper has also been prepared with regards to the study phase of the project. A copy of the paper is attached to this report as Appendix III. Presentations at the 1979 Promoters in Education Conference at Niagara Falls, N. Y. during October, 1979. The paper will be published in the proceedings of the conference.

SUMMARY STATEMENT OF EXPENDITURES

A statement of the budget, expenditure and balance in each account is shown in Fig. 2. Fig. 2 also contains information regarding expenditure through FY 79.

NO.	SUBJECT AREAS	AGNS	WESTINGHOUSE	ORNL	SNP	SRL	SCGEG	DUKE POWER
1	LICENSING OF NUCLEAR FACILITIES	S	M	S	S	S	H	H
2	QUALITY ASSURANCE FOR NUCLEAR FACILITIES	S	H	M	M	M	M	H
3	SAFEGUARDS	M	S	M	S	S	S	S
4	NUCLEAR FUEL CYCLE	S	M	M	M	S	M	M
5	SHIELDING	H	H	H	H	S	S	S
6	CRITICALITY	H	H	H	H	S	S	S
7	HEALTH PHYSICS	M	H	H	H	S	S	S
8	FUEL HANDLING AND TRANSPORTATION	S	M	M	M	S	S	M
9	REMOTE HANDLING			H	H			
10	DECOMMISSIONING OF NUCLEAR POWER PLANTS			H	H	H	S	M
11	ENVIRONMENTAL ASPECTS OF THE FUEL CYCLE	M	M	S	S	S		
12	UPDATE OF ENERGY PROGRAMS	H	H	H	H	H	M	M
13	INTERACTION OF NUCLEAR TECHNOLOGY AND PUBLIC POLICY	H	H	H	H	H	H	H
14	REACTOR SAFETY							
	a. INTRODUCTION TO REACTOR SAFETY	H	H	H	H	H	H	H
	b. NUCLEAR POWER REACTOR SAFETY		M	H	H	M	S	H
15	FIRE PROTECTION FOR NUCLEAR REACTORS		M	H	H	M	M	H
16	NUCLEAR FUEL MANAGEMENT	S	S	M	S	S	S	H
17	POWER COMPANY ECONOMICS	S	S	S	S	S	M	M
18	ELECTRONIC INSTRUMENTATION FOR NUCLEAR APPLICATIONS	M	M		M	H	M	H
19	ELECTRICAL ENGINEERING FOR NON-ELECTRICAL ENGINEERS			H	H	M		
20	STRUCTURED DESIGN OF COMPUTER SOFTWARE	S	M		M	M	S	H
21	PRACTICAL STATISTICS FOR NUCLEAR ENGINEERS	M	H	H			S	M
22	SYSTEM RELIABILITY ANALYSIS APPLICATIONS	M		H				
23	FAULT TREE ANALYSIS	M		H				
24	RADIATION EFFECTS ON MATERIALS			H	M	H		M
25	BASIC CONCEPTS OF CORROSION	H	H	H	H		H	M
26	WELDING METALLURGY, INSPECTION, AND DEFECT CONTROL		H	H	H			M
27	WELDING PROCESSES AND WELDING DESIGN			H	H			M
28	DESIGN AGAINST MECHANICAL FAILURE							
	a. PROCEDURES FOR DESIGN AGAINST FATIGUE			H	H		H	H
	b. FRACTURE MECH. APPROACH TO DESIGN AGAINST FATIGUE			H	H		H	H
	c. ANALYSIS OF MECHANICAL FAILURES			H	H		H	H
	d. STRESS ANALYSIS USING FINITE ELEMENT METHODS			H	H			H
29	METALLURGY OF STAINLESS STEEL AND NICKEL-BASE ALLOYS		H	H	H		S	M
30	HYDRAULICS AND FLUID MACHINERY	S	S	H	H	S	H	H
31	PRESSURE VESSEL AND PIPING CODES							
	a. ASME CODES - FAILURE MODES			H	H		H	H
	b. PRESSURE VESSEL DESIGN			H	H		S	H
	c. PIPING ANALYSIS			H	M		S	H
32	PROJECT ENGINEERING	S	S	H	M	M	M	H
33	TECHNICAL MANAGEMENT	S	S	H	M	M	M	M
34	TECHNICAL COMMUNICATIONS	S	S	M	S	M	M	M
35	PROCESS DESIGN & ANALYSIS FOR NUCLEAR FUEL REPRO.	M	S	H	H	S	S	M
36	CHEMICAL PROCESS DESIGN AGAINST ACCIDENTS	S	S	M	S	S		

FIG. 1. SUBJECT AREAS IDENTIFIED DURING THE STUDY - LEVEL OF INTEREST AT VARIOUS LOCATIONS IDENTIFIED AS:

H - HIGH

M - MEDIUM

S - SPECIALIZED

	May 1979	Expenditure thru June 30, 1979	Balance June 30, 1979	Outstanding Commitment thru 8/2/79	Estimated Balance Available Sept. 30, 1979
A. Salaries and Wages					
1. Professional Staff	13,800.00	6,732.99	7,067.01	3,609.00	3,458.01
2. Secretary	1,416.00	287.66	1,128.34	1,346.20	(217.66)
3. Staff Benefits	2,259.00	983.37	1,275.63	730.17	545.46
B. Other Direct Costs					
1. Travel	1,450.00	0.00	1,450.00	0.00	1,450.00
2. Learning Resources	500.00	0.00	500.00	190.00	310.00
3. Telephone	350.00	0.00	350.00	40.00	310.00
4. Postage, duplication and supplies	600.00	0.00	600.00	35.00	565.00
C. Total Direct Operating Costs	20,375.00	8,004.02	12,370.98	5,950.37	6,420.61
D. Indirect Costs	8,369.00	3,650.74	4,718.26	2,576.70	2,141.56
E. Total Project Cost	28,744.00	11,654.76	17,089.24	8,527.07	8,562.17

Fig. 2 Summary Statement of Expenditure identified for implementation activity through FY 79

APPENDIX A

NUCLEAR FUEL CYCLE

4. NUCLEAR FUEL CYCLE

- I. Course Description: An overview of the entire nuclear fuel cycle from mining to waste management including alternative process technologies. Discussion will include alternate fuel cycles, the effect of alternate fuels on process technology and process chemistry.
- II. Course Objectives: Familiarize the student with the chemistry and the process technology of the nuclear fuel cycle. He will be able to understand the overall fuel cycle and the relationship between each subprocess step to the overall cycle.
- III. Prerequisites: An undergraduate degree
- IV. Course Outline:
 - A. Introduction
 1. Resources - availability and limitations
 2. Alternate reactor cycles
 - a. LWR
 - b. gas cooled convertors HTGE
 - c. breeder reactor
 - i. LMFBR
 - ii. gas cooled breeders GCFBR
 - iii. LWBR
 - d. Heavy water reactors (i.e. CANDU)
 3. Alternate fuel cycles with and without recycle
 - a. U-Pu
 - b. U-Th
 - B. Mining and Milling
 1. Mining
 2. Milling
 - a. extraction
 - b. concentration and purification
 - c. product preparation
 3. Radioactivity released
 4. Low-grade ores
 5. Costs of reducing radiation doses

- C. Conversion of uranium concentrate to UF_6
 - 1. Processes
 - a. dry process
 - b. wet process
 - 2. Radioactivity released
 - a. dry process
 - b. wet process
 - 3. Costs of reducing radiation doses
- D. Uranium isotope separation
 - 1. Separation processes
 - a. gaseous diffusion
 - b. gas centrifugation
 - c. other methods
 - 2. Radioactivity released
 - 3. Doses to the public
- E. Fuel fabrication
 - 1. Processes
 - a. processes for enriched uranium
 - b. recycle fuel
 - c. cladding
 - 2. Radioactivity released
 - a. enriched uranium processes
 - b. recycle fuel
 - 3. Costs of reducing radiation doses
 - a. enriched uranium processes
 - b. recycle fuel processes
- F. Nuclear reactor technology
 - 1. LWR
 - a. PWR
 - b. BWR
 - 2. LMFBR
 - 3. HTGE
 - 4. Heavy water reactors
- G. Fuel reprocessing
 - 1. Nature of LWR fuel

2. Separations process
 - a. purex process
 - b. waste treatment
 - c. advanced method for specific isotopes
 3. Fuel reprocessing plant
 4. Radioactivity released
 5. Costs of reducing radiation doses
- H. Transportation
1. Uranium concentrate
 2. UF_6 to and from enrichment plants
 3. Fabricated fuel
 4. Spent fuel and reprocessing wastes
 - a. spent fuel
 - b. reprocessing wastes
 5. Relationship of shipping to siting
 6. Transportation accidents
- I. Waste management
1. Sources of radioactive wastes
 - a. mills
 - b. fabrication plants
 - c. reprocessing plants
 - d. nuclear reactors
 2. Waste treatment
 - a. decay
 - b. solidification
 - c. partitioning of actinides
 3. Geologic isolation
 4. Other disposal options
 5. Radioactive release
 - a. dose levels
 - b. costs of reducing dose
- J. Licensing and safeguards
1. Standards for release of radioactive materials from nuclear fuel cycles
 2. Standards for licensing non-irradiated fuel facilities
 3. Standards for licensing radiated fuel facilities

V. Course Format: This material can be presented as a three credit hour graduate/undergraduate course.

VI. Comments:

- A. A discussion will be given under each topic indicating the present and future adequacy of each particular area in view of anticipated expansion of nuclear power.
- B. This course material content is very ambitious even for a three hour credit course. Much discretion must be used in choosing the depth of treatment in each case.

4. NUCLEAR FUEL CYCLE

1. Elements of Nuclear Reactor Design, Weisman, Jr., Elsevier Scientific Pub. Co., N. Y. 1977.
2. Engineering for Nuclear Fuel Reprocessing, Long, J. T., Gordon and Breach Science Publishers, Inc., N. Y. 1967.
3. Technology of the Light Water Reactor Fuel Cycle, Wymer, R. G., Presented at University of South Carolina, Feb. 17, 1977.
4. Biological Processes for Environmental Control of Effluent Streams into Nuclear Fuel Cycle, Shumate, S.E., Hancher, C. W., Standberg, G. W., Scott, C. D., ORNL CONF-780316-7, 1978.
5. Internalizing Social Costs in Power Plant Sitings: Some Examples for Coal and Nuclear Plants in the United States, Peelie, E. ORNL, CONF-761103-16, 1976.

PROBLEMS FOR SOLUTIONUranium Enrichment

1. Natural uranium (0.711% U-235) is enriched to 3% U-235 in a gaseous diffusion cascade. Determine (a) the number of ideal stages required if the uranium is in the form of gaseous uranium hexafluoride (UF_6), and (b) the separative work units (SWU) required. Assume 0.25% U-235 remains in the tailings.
2. Natural uranium in the form of UF_6 costs \$35 per kg of uranium and cost of enrichment is \$46 per SWU. Determine the cost of one kg of uranium enriched to 3.1% U-235 for (a) 0.20% U-235 in the tailings and (b) 0.25% U-235 in tailings.
3. A nuclear fuel reprocessing plant recovers 1500 metric tons of uranium per year from spent fuel. The uranium has an average U-235 content of 0.84%. The uranium is enriched to 2.85% to fuel LWR. Determine (a) the mass of fuel that can be obtained and (b) the separative work units (SWU) required for enrichment by gaseous diffusion. Assume 0.25% U-235 in the tailings.
4. 1600 metric tons of low enrichment uranium is needed per year to fuel nuclear electrical generation plants. If the average enrichment is 3.1% U-235 and 0.25% U-235 is contained in the tailings, determine (a) the mass of natural uranium feed required, (b) the separative work units (SWU) of enrichment and (c) the total cost of the enriched uranium. Assume natural costs \$35/kg and enrichment costs are \$46/SWU and that only natural uranium is used.
5. In Problem (4) above, determine the power required to operate the enriching plant. Enriching plants require approximately 3070 kw-hr/SWU. Assume that the enriching plant is operated continuously at 100% capacity.

6. 100 metric tons of enriched uranium with an average enrichment of 2.8% are required to fuel a lightwater reactor. Reprocessed fuel having an average enrichment of 0.84% and natural uranium (0.71% U-235) are available. Determine the mass of (a) reprocessed uranium and (b) natural uranium that would be enriched to fuel the reactor. Assume that 0.25% U-235 is contained in the tailings.
7. In Problem (6) above, compare the cost of using reprocessed fuel with that of natural uranium. Assume that the reprocessed fuel and natural uranium costs \$36/kg and \$32/kg respectively and the enriching costs are \$46/SWU.
8. Uranium with 3.1% U-235 is to be obtained by enriching fuel from a nuclear fuel reprocessing plant with an enrichment of 0.8% and natural uranium (0.711% U-235). One kg reprocessed uranium is fed for each kg of product and tailings contain 0.3% U-235. Determine the mass of natural uranium required per kg of product and the separative work units required.

9. Uranium with 3.1% U-235 is obtained by enriching reprocessed fuel with an enrichment of 0.8%. The reprocessed fuel also contains 0.875% U-236. Determine the U-236 concentration in the product. Assuming the U-235 concentration in the tailings is 0.2%.

10. Uranium with 3.1% U-235 is obtained by enriching reprocessed fuel with 0.8% U-235 and natural uranium (0.711% U-235). The reprocessed uranium also contains 0.875% U-236. One kg of reprocessed uranium is fed for each kg of product and tailings 0.25% U-235. Determine the mass of natural uranium required per kg of product and concentration of U-236 in the product.

11. Natural uranium in the form of UF_6 is enriched in a Zippe gas centrifuge. Determine the equilibrium separation factor between gas at the axis of the centrifuge and gas at the peripheral for a centrifuge operating at 60°C and with a peripheral velocity of 350 m/sec.
12. Natural uranium in the form of UF_6 is enriched in a Zippe type gas centrifuge. The rotor has a length of 30 cm, a diameter of 8 cm, and a rotational speed of 90,000 rpm. The operating temperature is 80°C . Determine (a) the equilibrium separation factor of the centrifuge and (b) the maximum separative capacity in gm/day of the gas centrifuge. Assume diffusion parameter c_D equals 1.2×10^{-6} gm-mole/sec-cm

Spent Fuel Reprocessing

1. The fuel storage pool at a reprocessing plant store 250 metric tons of

spent fuel. The decay heat generation is 35 kw/kg and the cooling is provided by a cooling tower. If cooling water leaves the storage pool at 105°F and returns at 80°F, determine the cooling water flow rate in kg/min.

2. Spent fuel enters the dissolver at a rate of 250 kg/hr where the uranium, plutonium, and fission products are dissolved in HNO_3 . Uranium dissolution takes place by the reaction $3\text{UO}_2 + 8\text{HNO}_3 \rightarrow 3\text{UO}_2(\text{NO}_3)_2 + 4\text{H}_2\text{O} + 2\text{NO}$. Determine (a) the rate HNO_3 required for the reaction in kg/hr and (b) the rate of NO discharge in the offgas. Assume the spent fuel material entering the dissolver is primarily uranium.
3. One metric ton of spent fuel is dropped into the dissolver basket. The reaction equation of the UO_2 with HNO_3 is given in Problem 2. Assuming that the fuel is primarily UO_2 , determine the mass of HNO_3 required for each basket of dropped fuel.
4. The high-level waste concentration system concentrates the high-activity waste which contain most of the fission products from spent fuel assemblies. The wastes are concentrated to approximately 150 gallons per metric ton of spent fuel. Assuming decay heat generation is 35 kw/kg, determine the heat generation rate in a 1000 gallon surge tank containing the waste.
5. A solvent containing 30% by volume TBP is contained in a kerosene diluent extracts uranium from an aqueous solution. Determine the percent loading of the TBP when the solvent contains 80 gms/liter of uranium.
6. High-level wastes from a 1500 metric ton per year reprocessing plant are contained in underground storage tanks. Cooling of the tanks is provided by circulating water cooling coils. The water enters at 80°F and exits at 105°F. If the fuel decay heat dissipation is 9.0 kw/MTU, determine the cooling water flow required to the high-level waste

ADDITIONAL REFERENCES IN NUCLEAR FUEL CYCLE

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2. Aqueous Reprocessing Chemistry for Irradiated Fuels Symposium, Brussels, 1963.
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7. Shacter, J., E. Von Halle and R. L. Hoglund, "Diffusion Separation Methods," Encyclopedia of Chemical Technology, Vol. 7, 1965, pp.91-176.
8. Pechin, W. H., et. al., "Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing as Low as Practicable Grinder - Fabrication of Light-Water Reactor Fuel from Enriched Uranium Dioxide," ORNL-TM-4902, May 1975.
9. Groenier, W. S., et al, "Correlation of Radioactive Waste Treatment Costs and the Environmental Impact of Waste Effluents in the Nuclear Fuel Cycle for Use in Establishing as Low as Practicable Grinder - Fabrication of Light-Water Reactor Fuels Containing Plutonium," ORNL-TM-4904, May 1975.
10. Kaufmann, A. R., Nuclear Reactor Fuel Elements - Metallurgy and Fabrication, Interscience Publishers, N. Y., 1962.

APPENDIX B

METALLURGY OF STAINLESS STEEL AND NICKEL-BASED ALLOYS

29. METALLURGY OF STAINLESS STEEL AND NICKEL-BASE ALLOYS

- I. Course Description: This course presents the classification, strengthening mechanisms, mechanical properties, corrosion properties, and irradiation effects of both stainless steels and Nickel-base alloys. These materials are widely used in nuclear related applications when elevated temperatures or corrosion resistance are important.
- II. Course Objectives: This course is intended to provide a better understanding of these materials in service applications, material selection, control of mechanical and physical properties, fabrication, and design.
- III. Prerequisites: Undergraduate degree in engineering with at least one course in basic materials science.
- IV. Course Outline:
 - A. Stainless steels
 1. Classification
 2. Strengthening mechanisms, heat treatment, and microstructure
 3. Mechanical properties
 4. Corrosion properties
 5. Irradiation effects
 - B. Nickel-based alloys
 1. Range of alloys
 2. Strengthening mechanisms, heat treatment, and microstructure
 3. Mechanical properties
 4. Corrosion properties
 5. Irradiation effects
 - C. Considerations in welding stainless steels and nickel-base alloys
- V. Course Format: The one to two day traditional course format should be adequate. If greater depth of coverage is to be considered, the course could also be extended over a 3-5 day schedule. Following this latter format, the course would preferably be spread out over a series of weeks to allow time between instruction for independent study. Course material could be selected from manufacturers product literature for stainless steel and nickel-base alloys.

29. METALLURGY OF STAINLESS STEEL AND NICKEL-BASE ALLOYS

1. Metals Handbook, 8th ed., Vol. 1., "Properties and Selection of Metal," American Society for Metals, 1961.
2. Structure and Properties of Engineering Materials, 4th ed., R. M. Brick, A. W. Pence, and R. B. Gordon, 1977, McGraw-Hill.
3. Source Book on Stainless Steels, American Society for Metals, 1976.
4. The Inconel Alloys and Other Nickel-Base Alloys, 2nd ed., W. Betteridge and J. Heslop, Crane-Russak Co., 1974.
5. The Superalloys, edited by C. T. Sims and W. C. Hogel, Wiley, 1972.
6. Handbook of Stainless Steels, D. Peckner, McGraw-Hill, 1976.
7. Materials in Nuclear Reactors, C. O. Smith, Addison-Wesley, 1967.
8. Engineering Properties of Nickel and Nickel Alloys, edited by J. L. Everhart, Plenum, 1971.
9. Welding Metallurgy of Stainless and Heat Resisting Alloys, R. Castro and J. J. de Cadonet, Cambridge University Press, 1974.

REVISED COURSE OUT-LINE-
STAINLESS STEELS
AND NICKEL-BASED ALLOYS

A. Stainless Steels

1. Introductory Topics
 - a. History and Applications
 - b. Metallurgy of Steels - the Fe-C alloy system
 - c. Metallurgy of Stainless Steels - the Fe-Cr and the Fe-Cr-Ni Systems
2. Classification
 - a. Ferritic and Martensitic Grades
 - b. Austenitic Grades
 - c. Other Types of Stainless Steels including Precipitation Hardenable Grades
 - d. Heat Treatment and Control of Mechanical Properties
3. Selection
 - a. Alloying Elements in Stainless Steel
 - b. Wrought vs. Cast Stainless Steels
 - c. Elevated Temperature Service
 - d. Corrosion
 - e. Substitutability

B. Nickel-Base Alloys

1. Introductory Topics - History and Applications
2. Alloy Practice
 - a. Range of Alloys
 - b. Heat Treatment and Control of Mechanical Properties
3. Examination of Selected Alloy Types
4. Selection
 - a. Elevated Temperature Service
 - b. Corrosion Resistance
 - c. Oxidation Resistance

5. Core Histories Involving Nickel-Base Alloy Applications

C. Metallurgical Considerations in Welding Stainless Steels and Nickel Base Alloys

1. Examination of Applicable Welding Techniques
2. Welding and Control of Mechanical and Physical Properties

D. Effects of Irradiation

ADDITIONAL REFERENCES - METALLURGY OF STAINLESS STEELS
AND NICKEL-BASED ALLOYS

1. Nuclear Reactor Fuel Elements - Metallurgy and Fabrications, A. R. Kaufmann, Interscience, 1962.
2. Sourcebook on Materials for Elevated Temperature Applications, E. F. Bradley ed., American Society for Metals, 1979.
3. The Metallurgical Evolution of Stainless Steels, F. B. Pickering, American Society for Metals, 1979.
4. Metals and How to Weld Them, T. B. Jefferson and G. Woods, Lincoln Electric Co., Cleveland.