What can nuclear engineers learn from design studies? A review of the theory and evidence from contemporary American reactor design projects

Aditi Verma

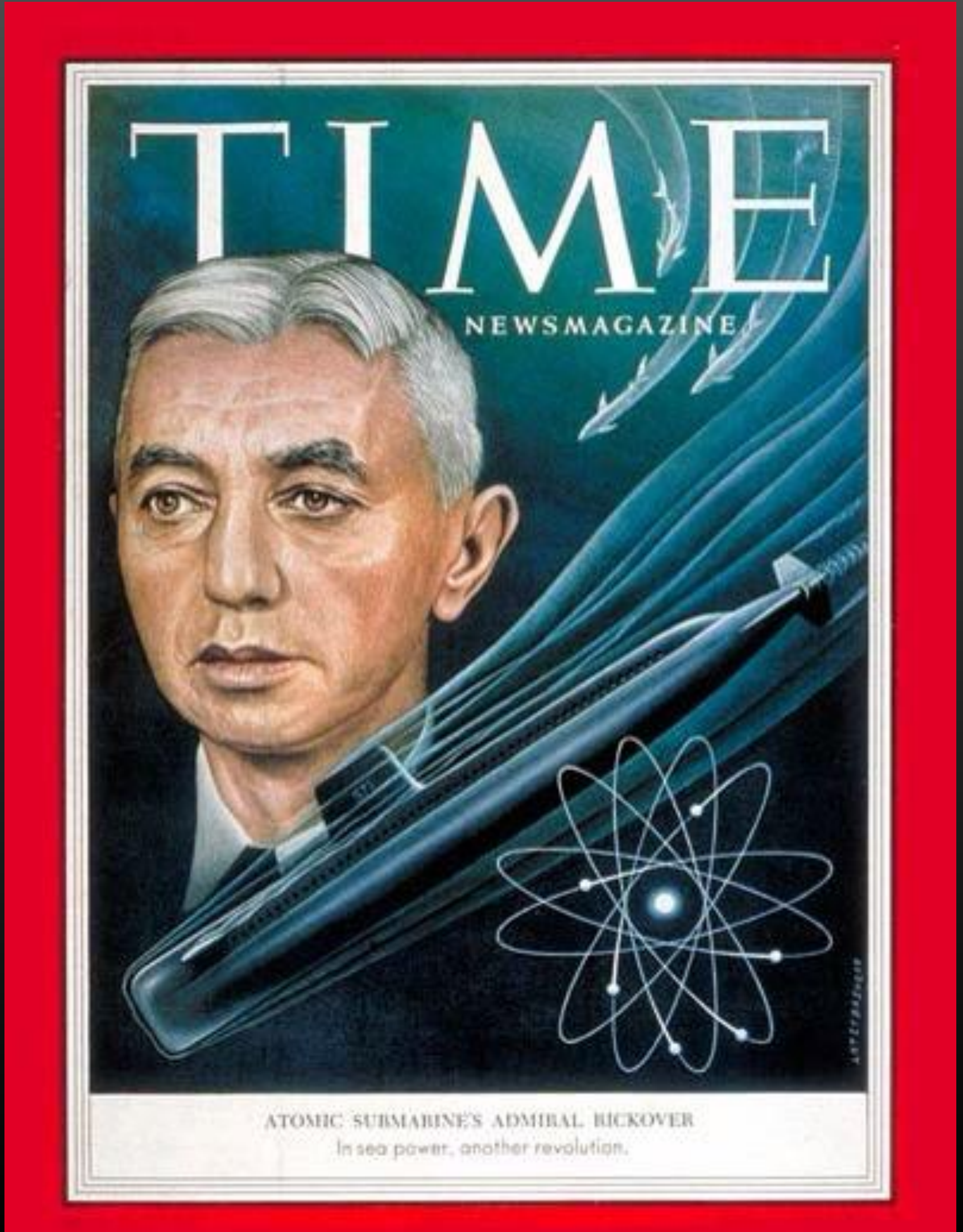
The nuclear and social science nexus: Challenges and opportunities for Speaking across the disciplinary divide

December 12-13 | OECD NEA

Hyman Rickover on reactor design (Rickover, 1953)

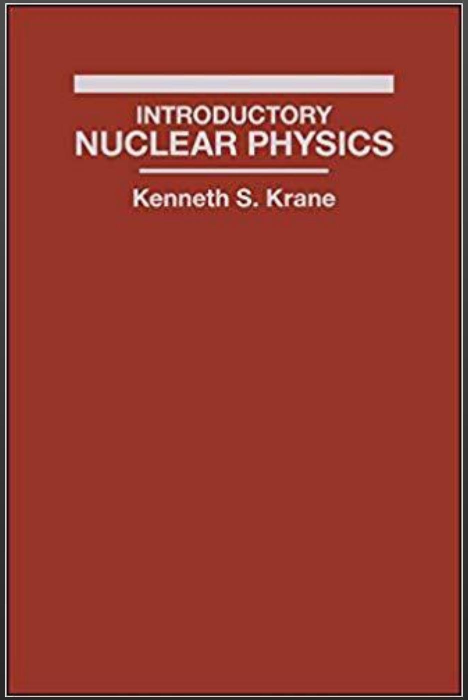
- Unlike a paper reactor, a “*practical reactor, is large, heavy, complicated and takes a long time to build because of engineering and development problems*”.

- *“The academic-reactor designer is a dilettante. He has not had to assume any real responsibility in connection with his projects. He is free to luxuriate in elegant ideas, the practical shortcomings of which can be relegated to the category of “mere technical details.” The practical-reactor designer must live with these same technical details. Although recalcitrant and awkward, they must be solved and cannot be put off until tomorrow. Their solutions require manpower, time and money.”*



Three views of design

This work compares and contrasts three views of design: those reported in the literature on design studies, those reported in academic nuclear engineering textbooks and finally, those reported by practitioner reactor designers.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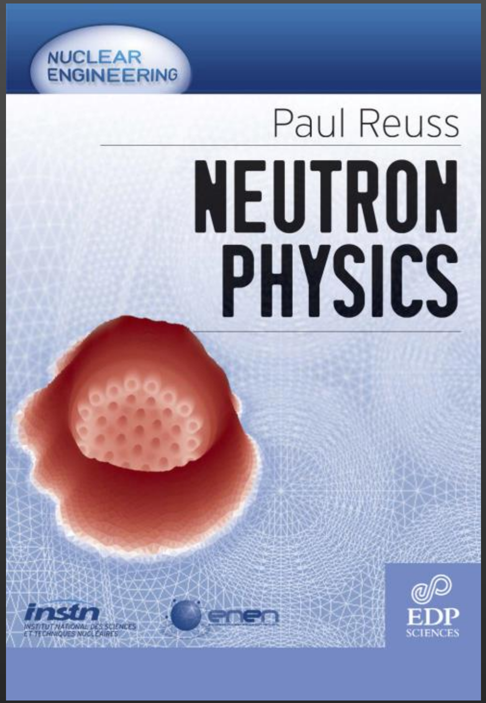
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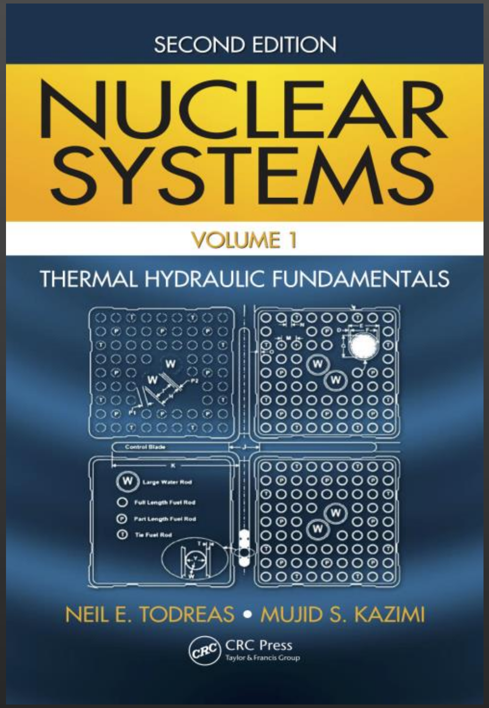
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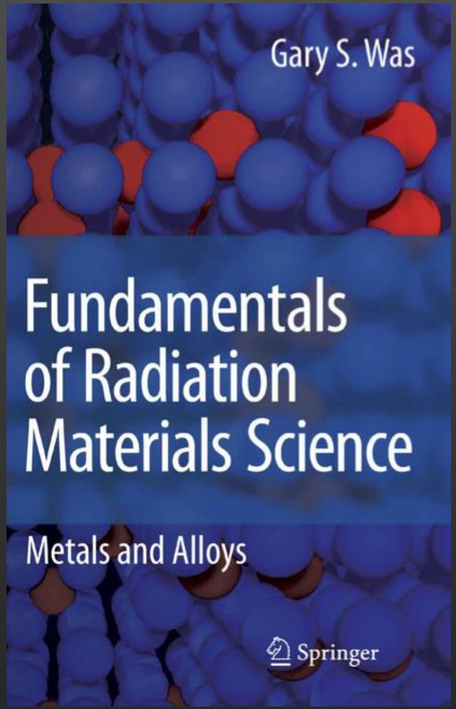
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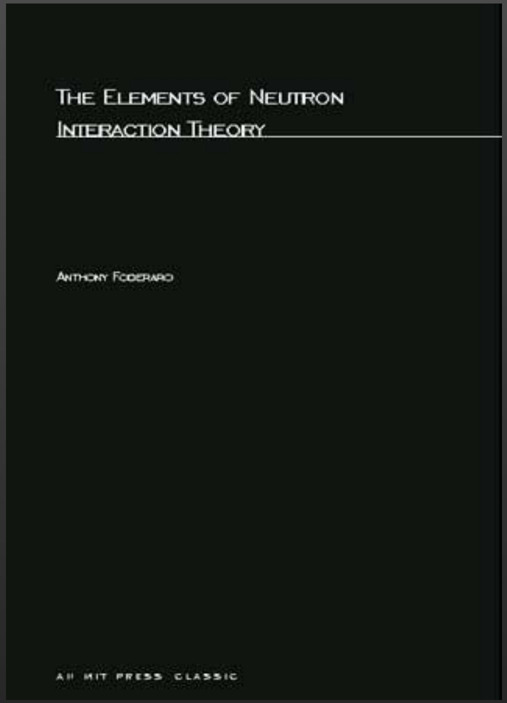
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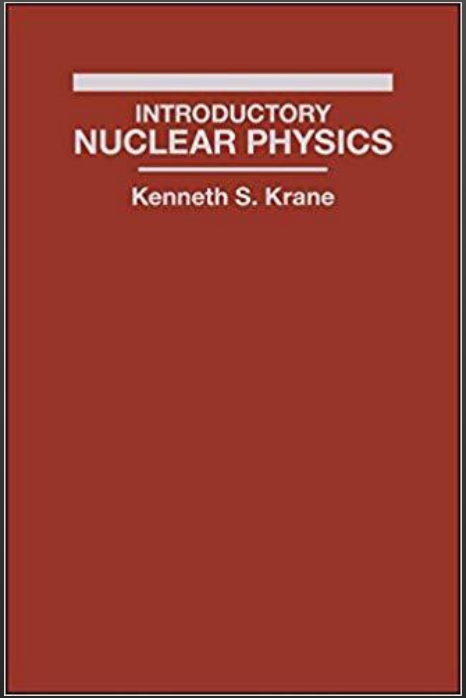
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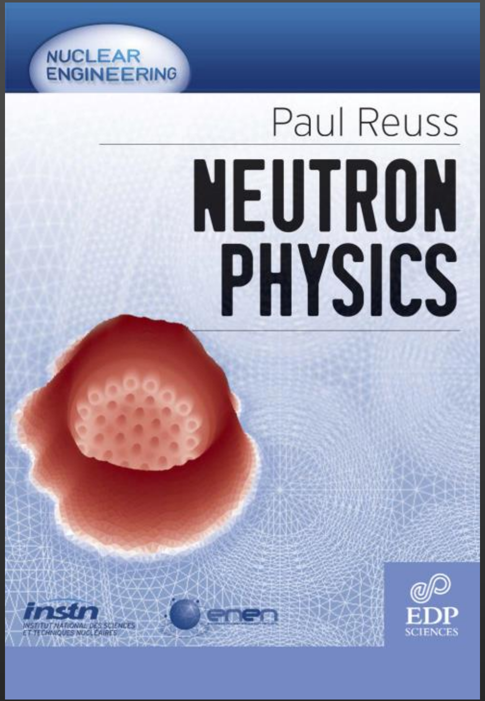
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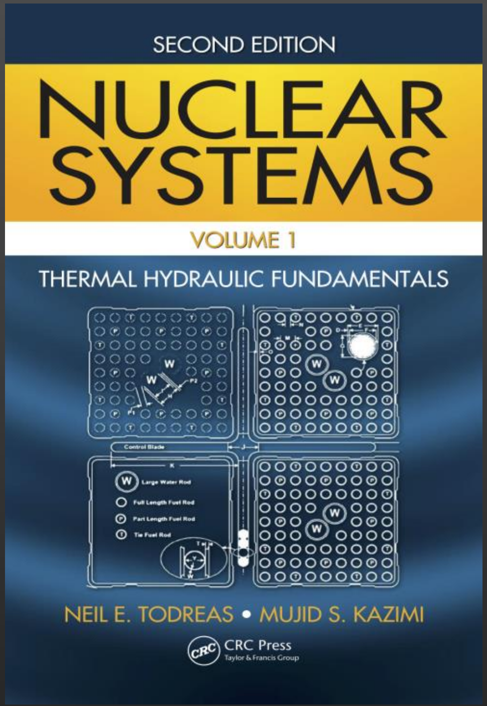
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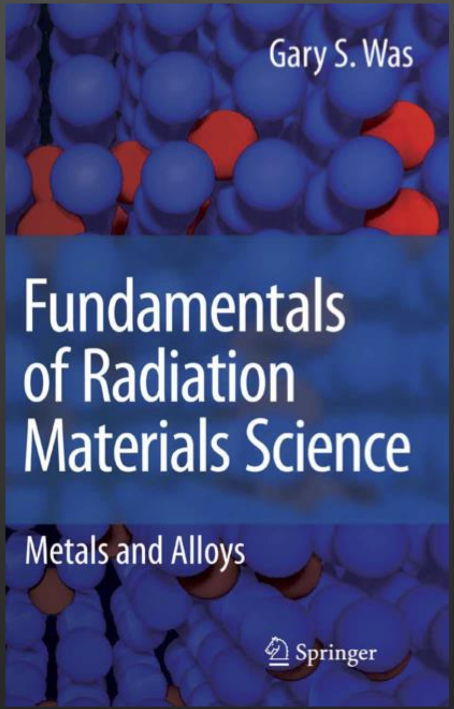
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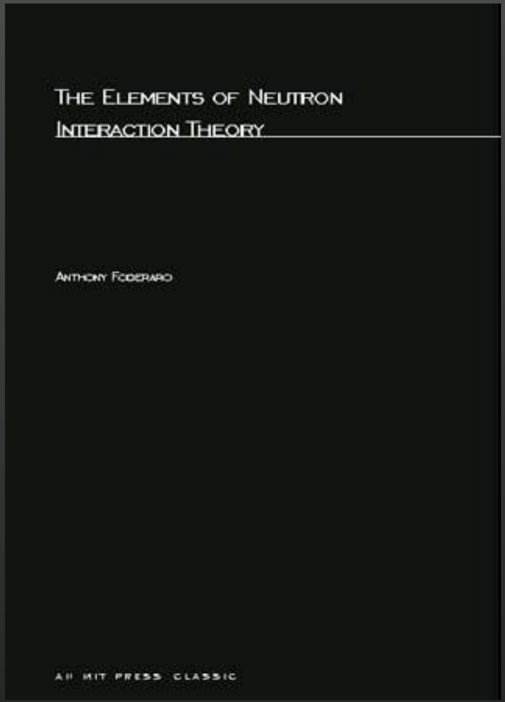
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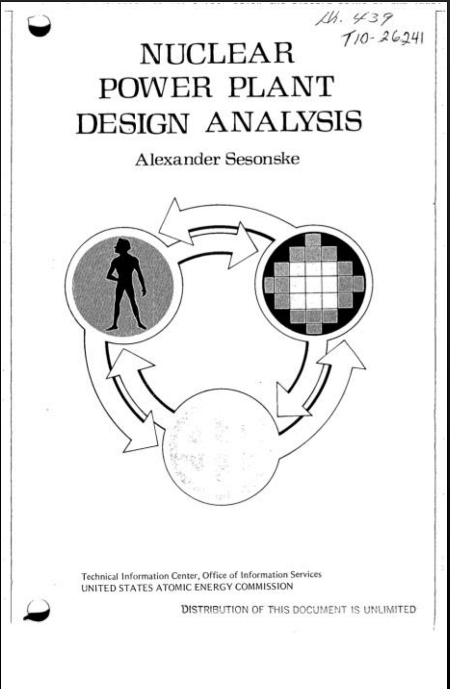
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Technical Information Center, Office of Information Services
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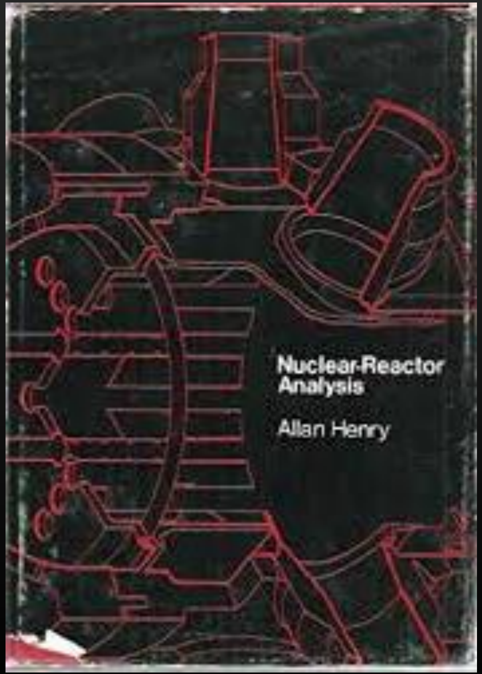
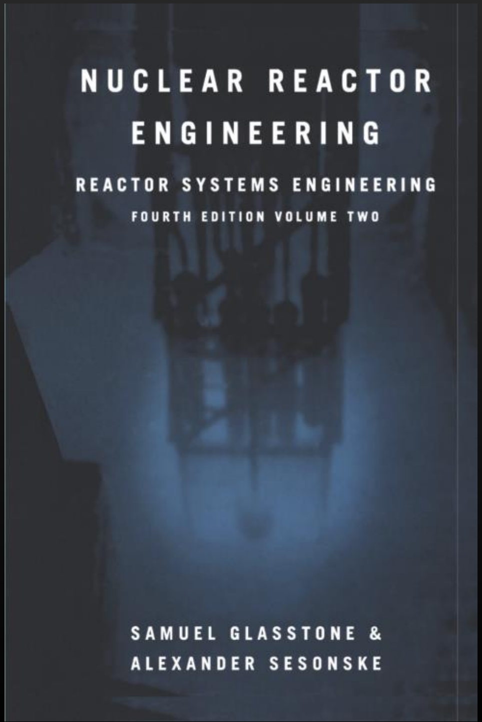

Nuclear-Reactor Analysis
Allan Henry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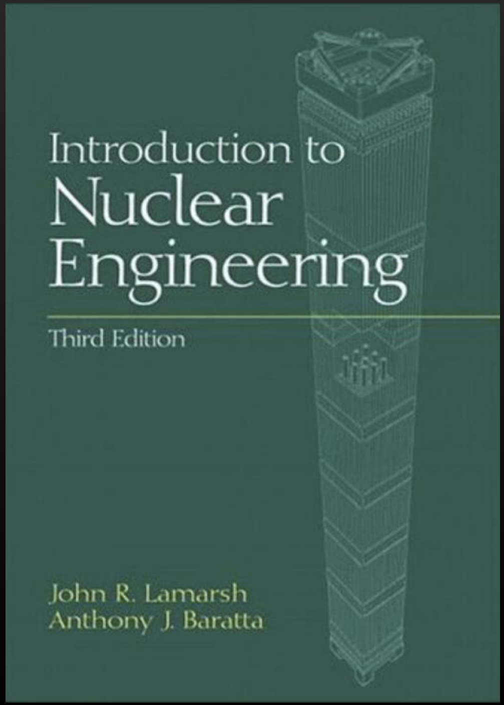
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Third Edition
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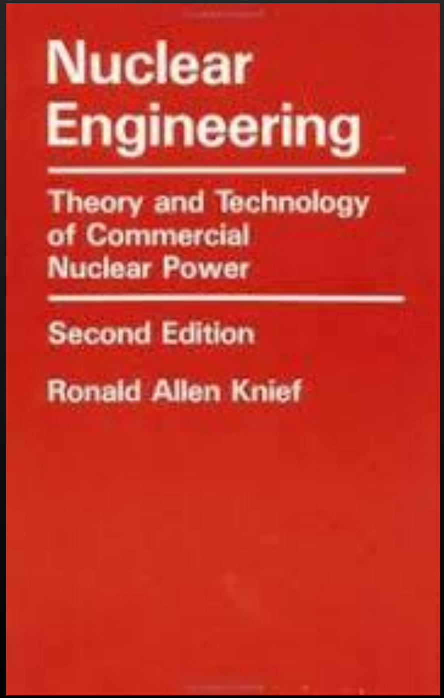
Nuclear Engineering
Theory and Technology of Commercial Nuclear Power
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Sesonske (1973) on design

- “The engineer's primary function is to create a structure, device, process, etc that will meet a practical requirement. The creative process required, known as design, can therefore be considered the very heart of engineering practice.”

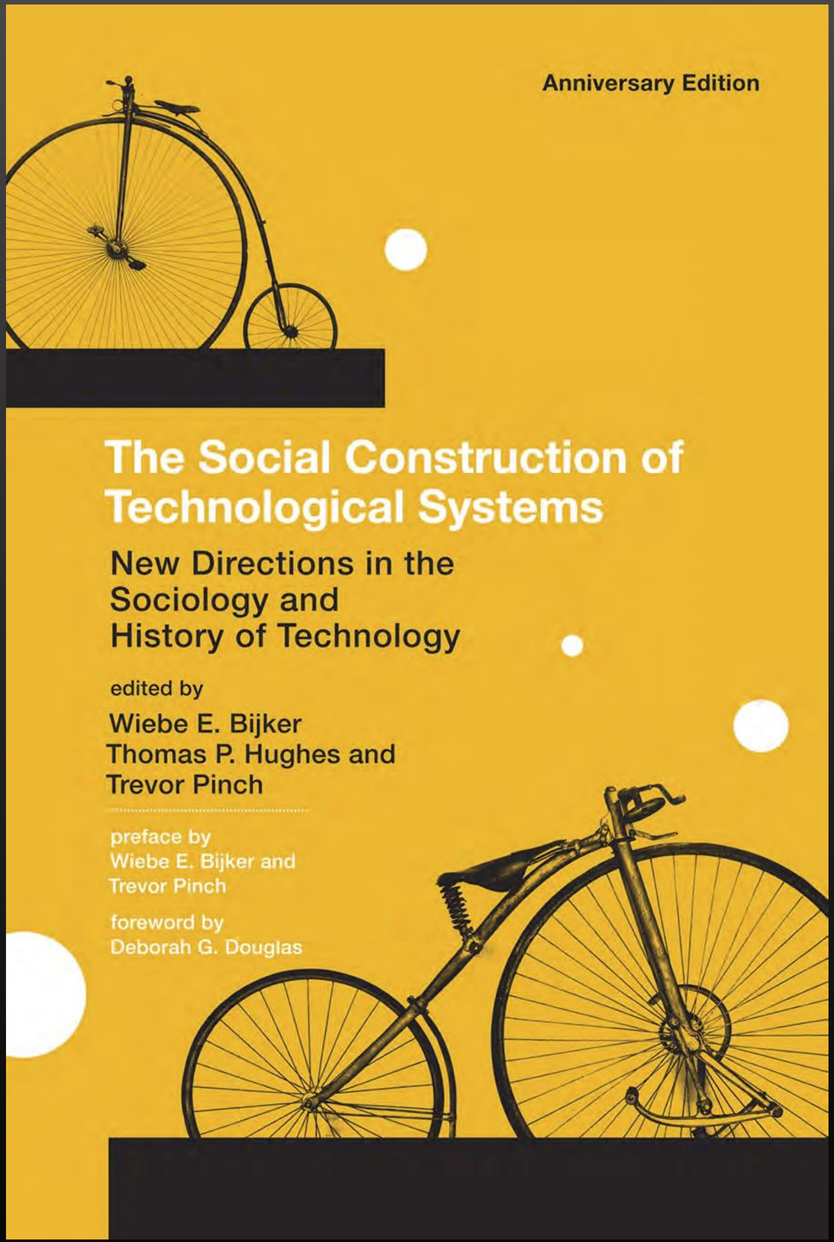
- “The design goal can be considered a “problem”, the solution of which proceeds through a number of logical steps. The initial step is to define the problem in a total way. This step includes sorting out of irrelevant information and of presently available solution approaches from the true nature of the problem to be solved. The next step is to analyze the problem, wherein the effects of various parameters and restrictions are evaluated.”

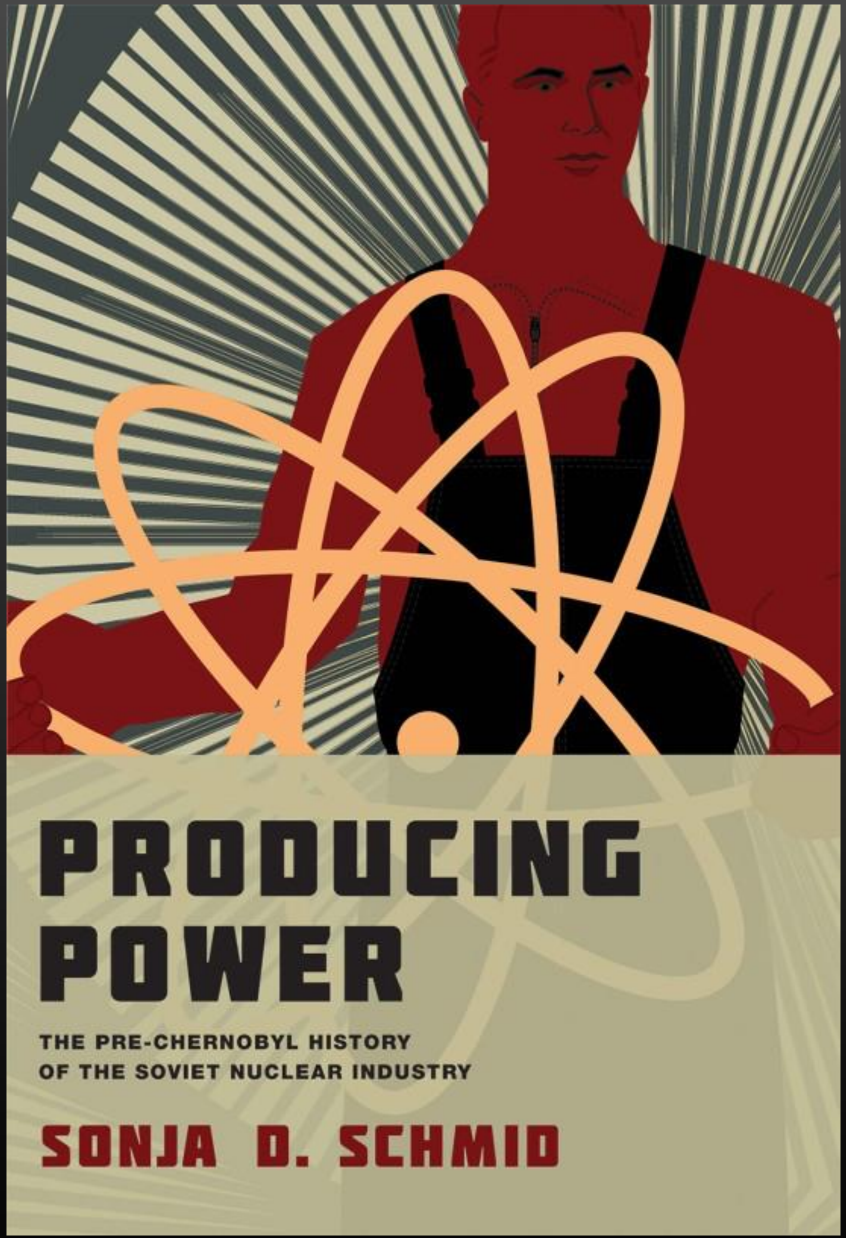
The argument

- The central goal of the paper is to show that design is far from the strictly analytical exercise described in nuclear engineering textbooks
- Instead, designers, in practice, exhibit a diversity of approaches to reactor design
- **A need to broad the scope of nuclear engineering to include both design as well as studies *of* design as part of the academic canon**

Design as an object of study

STS





Design as an object of study

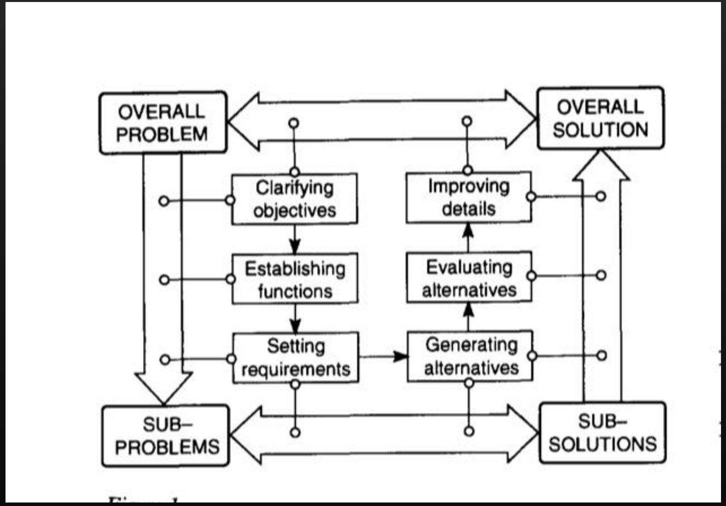
Design research

Design as an object of study

Models of the design process: integrating across the disciplines

N F M Roozenburg and N G Cross*

Department of Industrial Design Engineering, Delft University of Technology, Jaffalaan 9, 2628 BX Delft, The Netherlands



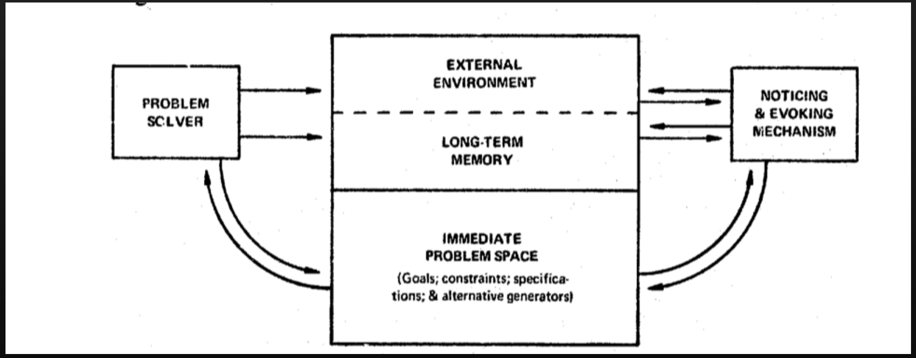
ARTIFICIAL INTELLIGENCE 181

The Structure of Ill Structured Problems*

Herbert A. Simon

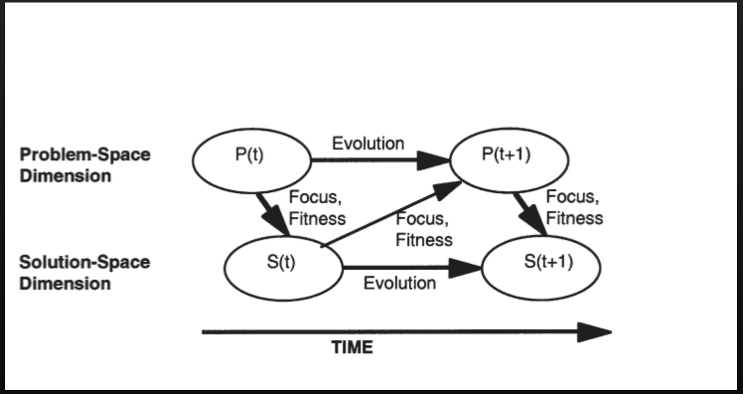
Carnegie–Mellon University, Pittsburgh, Pa.

Recommended by Saul Amarel



Creativity in the design process: co-evolution of problem–solution

Kees Dorst, Faculty of Industrial Design Engineering, Delft University of Technology, 2628 BX Delft, The Netherlands (Now at: Faculty of Technology Management, Eindhoven University of Technology, 5600 MB Eindhoven, The Netherlands)
Nigel Cross, Department of Design and Innovation, Faculty of Technology, The Open University, Milton Keynes MK7 6AA, UK



Methods

Reactors being developed in range of organizational settings

US	Russia	China	Japan	Korea	France	Canada	India	EU	UK	Argentina
AP1000	VVER 300	CEFR	4S	APR +	EPR	ACR-1000	AHWR	ALFRED	SSR	CAREM
ESBWR	VVER 440	CFR 600	APWR	APR 1000	Atmea	EC6	FBR	ALLEGRO	Ubattery	
ABWR	VVER 600	ACPR 1000	GTHTR300C	APR 1400	Kerena	Starcore HTGR	IPHWR 220	ELFR	Adams Engine	
NGNP	VVER 640	CAP 1000	IMR	PEACER	Astrid	LEADIR PS 100	IPHWR 700	HP-LWR		
IRIS	VVER 1000	CAP 1400	JSCWR	SMART	Flexblue	Dunedin SMART				
Westinghouse SMR	VVER 1200 V392M	CAP 150	JSFR	PGSFR	MSFR	Integral MSR				
NuScale	VVER 1200 V491	CNP 300	KAMADO FBR	KALIMER	NP 300					
mPower	VVER 1500	CNP 600	RBWR	ONPP	Antares					
Oklo	VBER 300	CNP 1000	LSPR	MMR						
Transatomic Power	SVBR 100	CPR 1000	MRX							
Terrapower TWR	KLT 40S	ACPR 1000	Fuji MSR							
Holtec SMR 160	BN 1200	CAP FNPP	RAPID							
S-PRISM	ANGSREM	CLEAR 1								
EM2	ELENA	HTR PM								
Offshore nuclear plant	MARS	HTR 200								
FHR	MTSPNR	HTR 600								
ThorCon	NIKA 70	NHR 200								
LFTR	RUTA 70	ACP 100								
SmAHTR	SAKHA 92	ACP 100S								
ARC 100	UNITHERM	ACP 10S								
Thorenco	SHELF	ACP 25S								
SSTAR	VK 300	ACPR 100								
GEMSTAR	VKT 12	ACPR 50S								
ENHS	ABV	FHR								
LC-E-SSTAR	BREST OD 300									
Hybrid Power technologies	RITM 200									
Xe-100										
G4M										
I2S-PWR										
Westinghouse LFR										
RADIX MMR										
Elysium MSR										
Terrapower MCFR										
Yellowstone energy										
eVinci										
Ultrasafe MMR-X										
Holos Gen										

Large company	55
Startup	27
National lab	31
University	11
Alliance	9

Interview methodology

- **27 reactor designs**
- **37 interviews (10 follow ups)**
- **length of interview : 1-3 hours**
- **400+ pages of interview transcripts**

Coded and analyzed using Atlas.ti and a grounded theory approach

additional sources of data : technical reports, conference and journal articles, regulatory documents, company websites, trade press, patents

Expertise and design choices

Expert designer – based in large company (small LWR) [H]

- The design company *"became interested in revisiting the notion of a smaller integral reactor because the history on the large commercial units was a lot of cost, a lot of overruns."*
- *"the feeling was that even back then that there would be considerable value in smaller modular units, that would be cheaper and could be built in a shop, the plant itself could be modularized and things like that.."*

Novice designer – based at a university, then startup (large non LWR) [P]

- *"So we started it from the perspective of …really what reactor would the public support and how do you alleviate the public's fears about nuclear power, especially the safety and waste issue. We felt like those were the biggest issues for nuclear. This was even before Fukushima which brought these issues into starker relief. "*

Expert vs novice designers

Tab. 4: Differences in design approaches

	Designers based in large companies (typically experienced designers)	Designers based in startups and universities (often young, first-time designers)
Problem framing	Accept dominant industry norms and framing of the design problem	Re-frame design problem and articulate the kinds of problems a new reactor design needs to solve
Decision about reactor technology to be developed	Typically start project with the reactor technology to be developed already selected	Typically start the project by explicitly evaluating what kind of reactor technology to develop
Stance towards previous designs	Typically use previous designs as starting point for work and defer to the rationale behind previous design choices	Often use previous designs as starting point for work but adopt a critical stance towards previous designs and design choices
Exploration of design space	New designs improve over previous ones; limited exploration and extension of design space	New designs improve over previous designs and also introduce novel systems; wider exploration and extension of design space
Outcome for safety	Evolutionary improvements in safety over previous designs	Potential for significant improvements in safety over previous designs and the introduction of new forms of safety

Implications for practice

- Reactor design *not* the purely analytical exercise as described in academic nuclear engineering textbooks
- The different approaches taken in the early stages of design by novice vs experienced designers working across a range of design settings suggest that there is significant value in adopting a more reflective approach towards the early stages of design
- **This work argues for broadening the scope of nuclear engineering to include both design as well as studies *of* design as part of the academic canon as such studies of design are likely to yield valuable insights for pedagogical purposes, practice and technology policy**

Appendix slides

Evolution of design studies

Experiential

Practitioners reflect on and self-report design approaches

Intellectual

Design becomes an object of study
Researchers begin to propose methodologies and principles for use by practitioners

Experimental

Study of design in controlled settings, to understand the determinants of design outcomes (role of expertise, design setting, problem framing, forms of representation)

Theoretical

Validation and testing of (sometimes competing) theories of design

Wallace, Ken M., and Luciënne TM Blessing. "Observations on some German contributions to engineering design in memory of Professor Wolfgang Beitz." Research in Engineering Design 12.1 (2000): 2-7.
Blessing, Lucienne. "What is this thing called design research?." DS 31: Proceedings of ICED 03, the 14th International Conference on Engineering Design, Stockholm. 2003.