The analysis of the effect of control rods on safty parameters of Tehran research reactor

NATIONAL
CENTRE
FOR NUCLEAR
RESEARCH
ŚWIERK

Mina Torabi

Division of Nuclear Energy and Environmental Studies

Mina.Torabi@ncbj.gov.pl

Fundusze Europejskie
Wiedza Edukacja Rozwój

Rzeczpospolita Polska

Unia Europejska
Europejski Fundusz Społeczny

New reactor concepts and safety analyses for the Polish Nuclear Energy Program
POWR.03.02.00-00.I005/17

outline

- Introduction
- Methodology
- Results and discussion
- Conclusion

Introduction

1.1 Description of TRR

Light water moderated

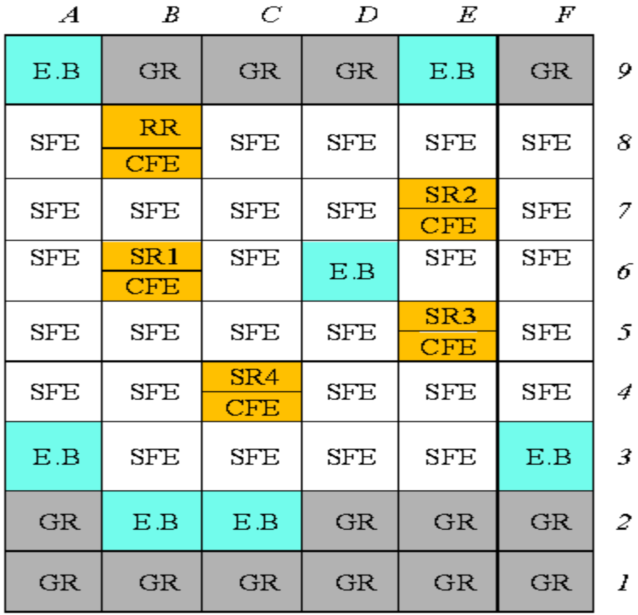
Solid fuel

Heterogeneous

Maximum thermal power 5MW

Pool type

Introduction



A	B	C	D	E	F	
E.B	GR	GR	GR	E.B	GR	9
SFE	RR CFE	SFE	SFE	SFE	SFE	8
SFE	SFE	SFE	SFE	SR2 CFE	SFE	7
SFE	SR1 CFE	SFE	E.B	SFE	SFE	6
SFE	SFE	SFE	SFE	SR3 CFE	SFE	5
SFE	SFE	SR4 CFE	SFE	SFE	SFE	4
E.B	SFE	SFE	SFE	SFE	E.B	3
GR	E.B	E.B	GR	GR	GR	2
GR	GR	GR	GR	GR	GR	1

SFE: STANDARD FUEL ELEMENT CFE: CONTROL FUEL ELEMENT
GR-BOX: GRAPHITE BOX E.B: EMPTY BOX
SR: SHIM SAFETY ROD RR: REGULATING ROD

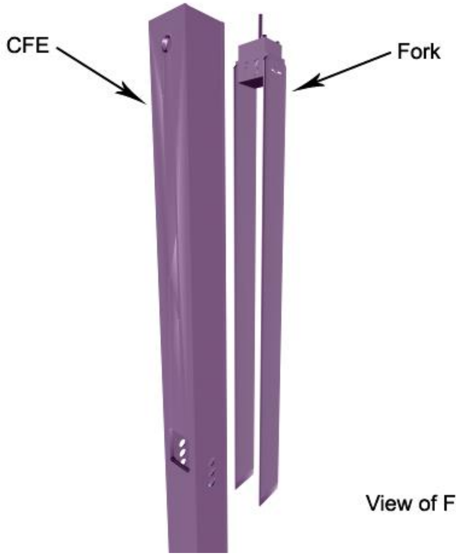
Fig.1.TRR 61 core configurations

Introduction

TRR Reactivity Control System:

four shim safety rods (Ag, In, Cd) + one stainless steel regulating rod within the core lattice

- Fork type
- Both of safety and regulating rods

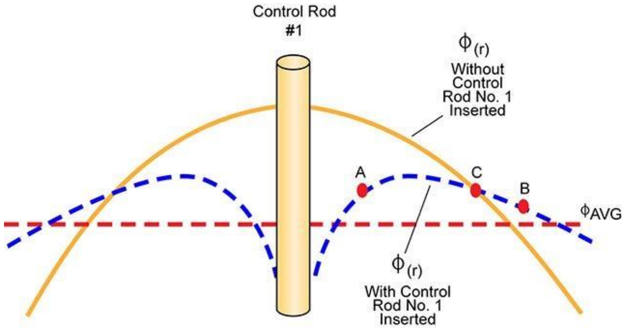


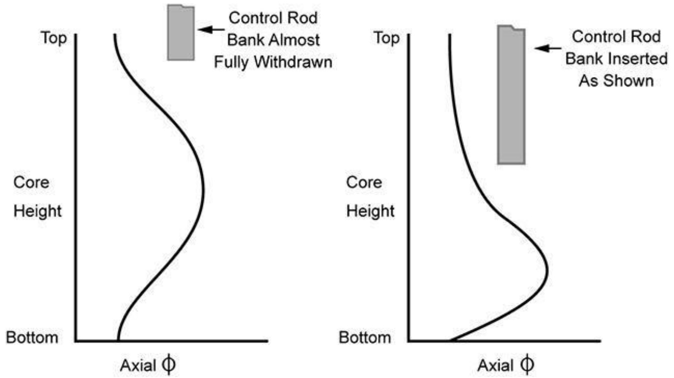
View of Fork and CFE

Introduction

Control rods

The effects of control rods on neutronic parameters & core safety





The main purpose:

The effect of control rods movement on the: reactivity coeficients, kinetic and P.P.F safty related parameters in TRR

Methodology

MTR_PC package:

In order to perform neutronic, thermal hydraulic and shielding calculation of MTR-type reactors

To calculate kinetic and neutronic parameters

- WIMSD-5B
- POS_WIMS
- HXS
- BORGES
- CITVAP v.3.1

Results and discussion

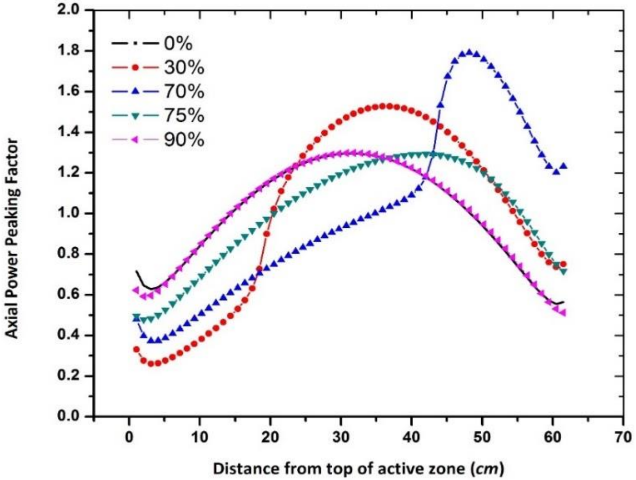
The effect of control rods position on P.P.F

- P.P.F = ρmax / ρave

High P.P.F: high local power densities in the reactor core

Hot channel or P.P.F(total)= P.P.F(axial)×P.P.F(radial)

- Axial PPF distributions in 0% and 90% and 70%



Results and discussion

- Behavior of the axial PPF is opposite of the radial PPF from 0-70%
- After 70% have a same increasing trend
- The total PPF increases by the rod positions, max in 45-70%
- PPFt max <3 (criteria in SAR)

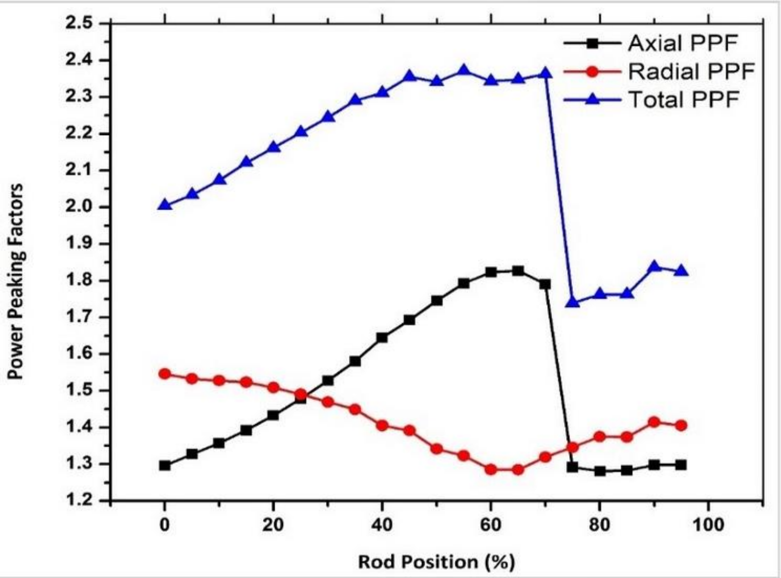


Fig.3.Variation of PPFs vs. rods position

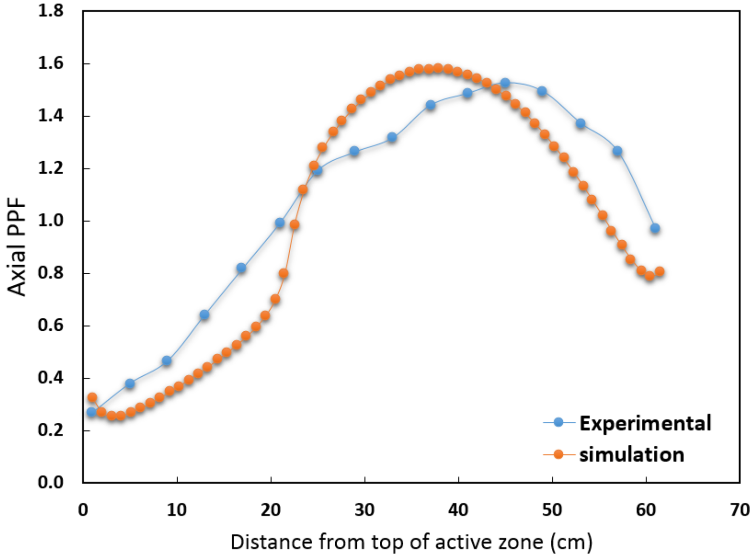
Results and discussion

- Experimental results: flux measurement
- The max experimental PPFa =1.5
- The simulation axial PPF value in 35% rod positions =1.6

  (this discrepancy is justifiable)
- Partial of this difference: the calculation and mesurment

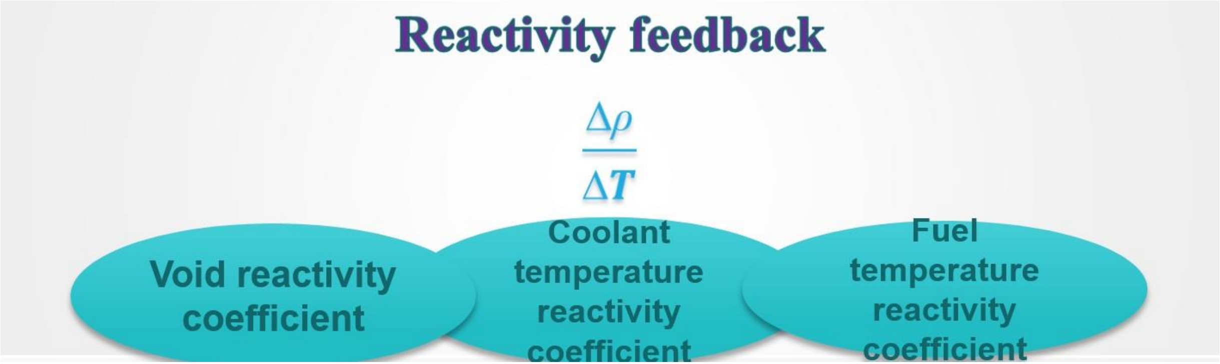
  errors
- Major difference : ununiformed burn-up of fuel assemblies

  due to control rods effect



Results and discussion

The effect of control rods on reactivity feedback



Reactivity feedback

$\frac{\Delta\rho}{\Delta T}$

Void reactivity coefficient

Coolant temperature reactivity coefficient

Fuel temperature reactivity coefficient

Results and discussion

- ☐ The value of average temperatures are varied in steps 20°C around the reactor operating temperature range of the components

- ☐ The value of reactivity feedback coefficient : reactivity changing due to temperature and void changing.

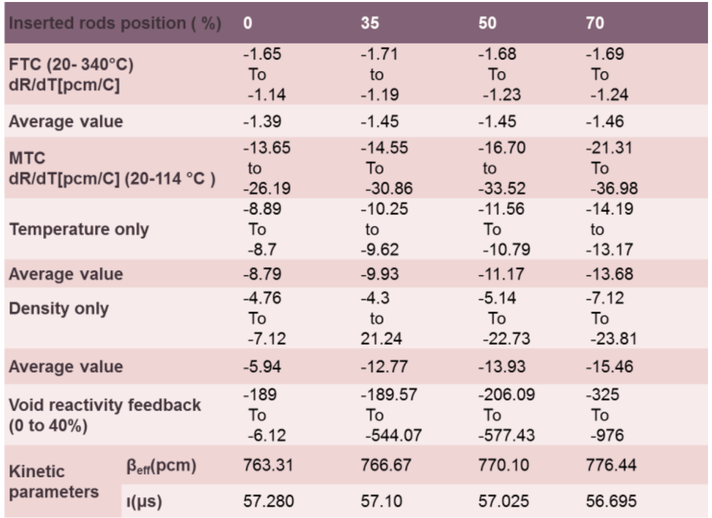
Results and discussion

Table 3. Reactivity coefficients in 61 core for positions of 0%,35%,50% and 70%

70	50	35	0	Inserted rods position (%)	
-1.69 To -1.24	-1.68 To -1.23	-1.71 to -1.19	-1.65 To -1.14	FTC (20- 340°C) dR/dT[pcm/C]	
-1.46	-1.45	-1.45	-1.39	Average value	
-21.31 To -36.98	-16.70 to -33.52	-14.55 To -30.86	-13.65 to -26.19	MTC dR/dT[pcm/C] (20-114 °C)	
-14.19 to -13.17	-11.56 To -10.79	-10.25 to -9.62	-8.89 To -8.7	Temperature only	
-13.68	-11.17	-9.93	-8.79	Average value	
-7.12 To -23.81	-5.14 To -22.73	-4.3 to 21.24	-4.76 To -7.12	Density only	
-15.46	-13.93	-12.77	-5.94	Average value	
-325 To -976	-206.09 To -577.43	-189.57 To -544.07	-189 To -6.12	Void reactivity feedback (0 to 40%)	
776.44	770.10	766.67	763.31	β_{eff}(pcm)	Kinetic parameters
56.695	57.025	57.10	57.280	ı(μs)	

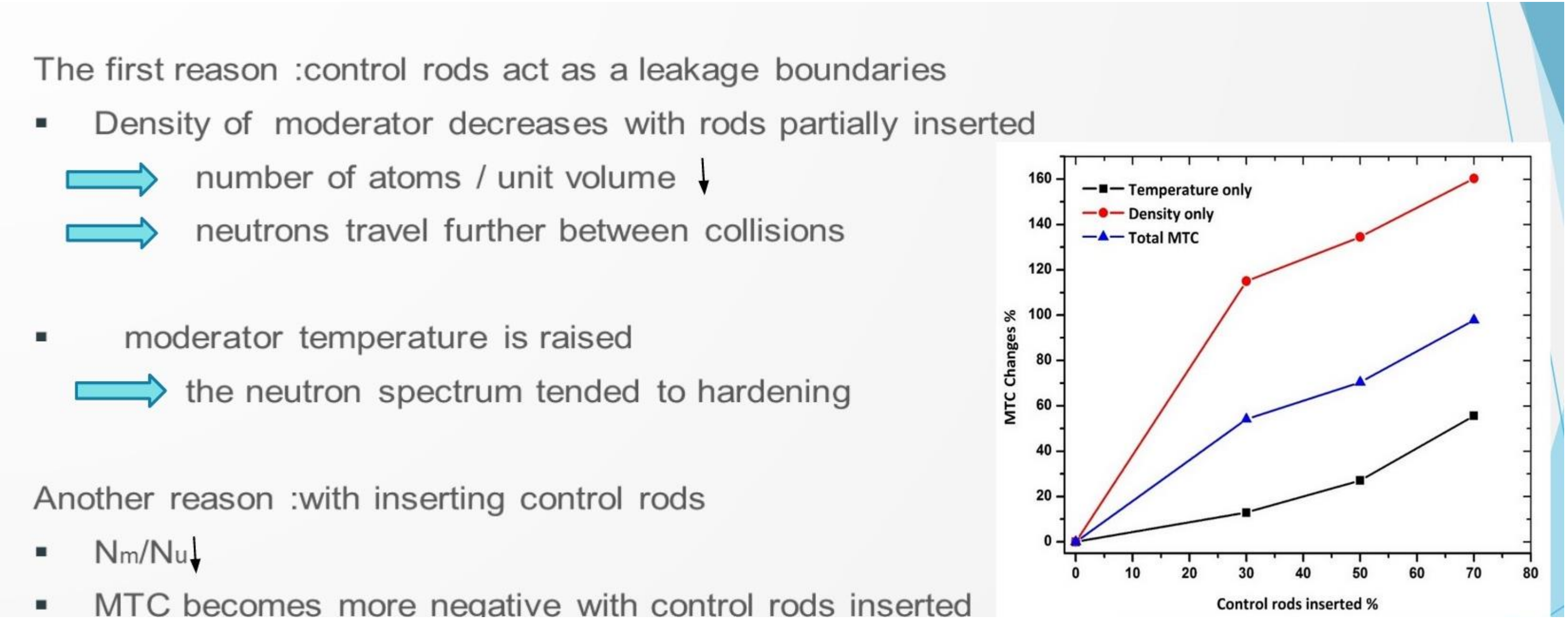
Results and discussion

- **Moderator Temperature Coefficient (α_m):**
- The reactivity change per degree change in moderator temperature
- MTR type reactor :negative MTC
- MTC: turning power down
- Moderator temperature was changed 20-114°C (densities were changed in accordance with temperature variations)
- To increase of $\alpha_{T,m}$ (56%) in the range of 0-70%
- $\alpha_{\rho,m}$ grows very rapidly
- ($\alpha_{T,m} + \alpha_{\rho,m}$) 98% increment in 70%



Inserted rods position (%)		0	35	50	70
FTC (20- 340°C) dR/dT[pcm/C]		-1.65 To -1.14	-1.71 to -1.19	-1.68 To -1.23	-1.69 To -1.24
Average value		-1.39	-1.45	-1.45	-1.46
MTC dR/dT[pcm/C] (20-114 °C)		-13.65 to -26.19	-14.55 To -30.86	-16.70 to -33.52	-21.31 To -36.98
Temperature only		-8.89 To -8.7	-10.25 to -9.62	-11.56 To -10.79	-14.19 to -13.17
Average value		-8.79	-9.93	-11.17	-13.68
Density only		-4.76 To -7.12	-4.3 to 21.24	-5.14 To -22.73	-7.12 To -23.81
Average value		-5.94	-12.77	-13.93	-15.46
Void reactivity feedback (0 to 40%)		-189 To -6.12	-189.57 To -544.07	-206.09 To -577.43	-325 To -976
Kinetic parameters	β_{eff}(pcm)	763.31	766.67	770.10	776.44
	ı(μs)	57.280	57.10	57.025	56.695

Results and discussion



The first reason :control rods act as a leakage boundaries

- Density of moderator decreases with rods partially inserted

⇨ number of atoms / unit volume ↓

⇨ neutrons travel further between collisions

- moderator temperature is raised

⇨ the neutron spectrum tended to hardening

Another reason :with inserting control rods

- N_m/N_u↓
- MTC becomes more negative with control rods inserted

Fig.5. Control Rod Position Effects on MTC

Results and discussion

Fuel Temperature Coefficient (α_f)

- FTC
- Responds quicker than MTC (reactor power causes an immediate increase in fuel temperature)
- The fuel temperature : 20-340°C
- Fuel temperature ↑ fuel reactivity coefficient ↓
- cause of resonance absorption for U_{238} and Pu_{240}
- The presence of control rods ↑ fuel reactivity coefficient ↑
- Replacing of moderator with absorber materials

Inserted rods position (%)	0	35	50	70
FTC (20- 340°C) dR/dT[pcm/C]	-1.65 To -1.14	-1.71 to -1.19	-1.68 To -1.23	-1.69 To -1.24

Results and discussion

Void reactivity Coefficient (αv)

- power increases to higher levels
- The effect of reducing the moderator density
- Different percentage of void from 0-40%
- αv increases with void percentage
- The main reason (loss in water density, reduces the neutron thermalization and increases the U238 resonant absorption)

αv increased with inserting the control rods positions (reason mentioned in the MTC part)

70	50	35	0	Inserted rods position (%)
-325 To -976	-206.09 To -577.43	-189.57 To -544.07	-189 To -6.12	Void reactivity feedback (0 to 40%)

Kinetic Parameters

- Little reduction in ι and increasing in β
- The reason: Shifting of average neutrons velocity to higher values
- Contribution of the thermal fission decreases and the fast fission increases
- ι↓& β↑ due to increasing U_{238} contribution in β

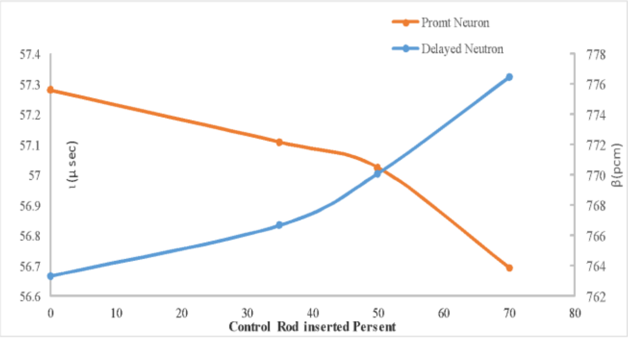


Fig.6. kinetic parameters verse control rods position (%)

70	50	35	0	Inserted rods position (%)	
776.44	770.10	766.67	763.31	β_{eff}(pcm)	Kinetic parameters
56.695	57.025	57.10	57.280	ι(μs)	

Conclusion

- PPFa ↑ & PPFr ↓ Until 70% rod position & After 70% have a same increasing trend
- PPFt reached to its max in 45% until 70%
- $a_{F,T}$ ↑ with increasing the control rods

$\alpha_{T,m}$ & $\alpha_{\rho,m}$ and total MTC increased about 56%,160% and 98% in the range of 0-70%

- α_v ↑ with increasing the control rods
- $\lfloor$ ↓ & β ↑ (reason: shifting of the average neutron velocity to higher values results in the control rods inserted increasing)

Literature

- 1. IAEA-TECDOC-1234, *The applications of research reactors. IAEA, Viana.* 2001.
- 2. IAEA, *SAFETY OF RESEARCH REACTORS.* IAEA SAFETY STANDARDS SERIES 2005. **NS-R-4**.
- 3. Lamarsh, J.R. and A.J. Baratta, Introduction to nuclear engineering. 2001.
- 4. Lashkari, A., et al., *Neutronic analysis for Tehran Research Reactor mixed-core.* Progress in Nuclear Energy, 2012. **60**: p. 31-37.
- 5. Lashkari, A., H. Khalafi, and H. Kazeminejad, Effective delayed neutron fraction and prompt neutron lifetime of Tehran research reactor mixed-core. Annals of nuclear energy, 2013. 55: p. 265-271.
- 6. Hetrick, D.L., *DYNAMICS OF NUCLEAR REACTORS.* 1971.
- 7. Mirza, A.M., S. Khanam, and N.M. Mirza, Simulation of reactivity transients in current MTRs. Annals of Nuclear Energy, 1998. 25(18): p. 1465-1484.
- 8. Kulikowska, T., *WIMSD-5B: A Neutronic Code for Standard Lattice Physics Analysis.* Distributed by NEA Data Bank. Saclay, France, 1996.
- 9. Lecot, E.V.a.C., Neutronic calculation code CITVAP 3.1.
- 10. Lashkari, A., et al., *Experimental study of neutronic parameters in Tehran research reactor mixed-core.* Progress in Nuclear Energy, 2015. **83**: p. 398-405.

Thank you for attention

NATIONAL
CENTRE
FOR NUCLEAR
RESEARCH
ŚWIERK

Mina Torabi

Division of Nuclear Energy and Environmental Studies

Mina.Torabi@ncbj.gov.pl

Fundusze Europejskie
Wiedza Edukacja Rozwój

Rzeczpospolita Polska

Unia Europejska
Europejski Fundusz Społeczny

New reactor concepts and safety analyses for the Polish Nuclear Energy Program
POWR.03.02.00-00.I005/17