

Overview of the RELAP5-3D code activities in ENEA

C. Parisi, P.Balestra, E.Negrenti, M. Sepielli

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 - OECD/NEA KALININ 3 benchmark
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Framework - ENEA & the SIMING Lab

- ENEA is the Italian National Agency for New Technologies, Energy & Sustainable Economic Development
- A branch of ENEA actively involved in researches for fission nuclear power technology
 - Research Reactors (e.g., TRIGA & Tapiro)
 - Experimental Engineering (e.g., AP600 components testing)
 - Nuclear Material Characterization
 - Models & Simulation
 - Integrated Services (e.g., waste management)
 - Metrology & Radioprotection
 - Advanced Nuclear Systems (e.g., Gen IV, LFR)
- The ENEA-SIMING Lab performing R&D activities NPP simulations & engineering simulators at the Casaccia Research Center (Rome)
- Acting as Technical Support Organization (TSO) for the Italian Nuclear & Industrial Safety Authority (ISPRA)



TRIGA Reactor (1 MW)



TAPIRO Fast Neutron Source





Recent activities using RELAP5-3D code



- RELAP5-3D code used for studying NPP transients and accidents
- Participating to coupled code benchmarks organized by OECD/NEA
 - "KALININ-3": VVER-1000 MCP-1 switch off @ HFP
 - "OSKARSHAMN-2": BWR Global Core Instability Event

Objectives:

- to explore the capabilities of the coupled codes in simulating NPP behavior during AOO/DBA
- to quantify codes and models uncertainties

Recent activities using RELAP5-3D code

KALININ-3 benchmark

- Model developed in the past years
- Presented in the last IRUG meeting
- Final results being submitted to the benchmark organizers by the end of the year
- Primary & secondary circuits modeled
 - 3D TH components for RPV
 - 3D NK core model
 - Detailed TH nodalization for selected FA
- Demonstrated capabilities of RELAP5-3D in modeling core asymmetric coolant temperature perturbations with high resolution degree





Recent activities using RELAP5-3D code



OSKARSHAMN-2 benchmark

- Launched by OECD/NEA last year → release 1.0 of specifications
 → definition of several parameters still in progress
- Previous instability benchmarks (Forsmarsk and Ringhals) characterized by decay ratio<1.0 & based on noise measurement of a stable reactor
- O-2 1999 event is an instability event with a DR>1 (diverging oscillation)
- Challenging simulation for a coupled code
 - Detalied RPV/core nodalization needed
 - Core parameters changing on a great magnitude
 - Core power going from 60% up to 130%
 - Tightly coupled NK-TH transient

The Oskarshamn NPP





Reactor Coolant System modelling





Design operating conditions										
Rated thermal power	MWt	1700								
Dome pressure	MPa	7.0								
Steam flow rate	kg/s	900.0								
Reactor pressure vessel geometry										
Internal height	m	20.0								
Internal diameter	m	5.2								
Weight	t	530.0								
Wall thickness	mm	134.0								
Cor	e geometry									
Equivalent core diameter	mm	3672								
Equivalent core height	mm	3712								
Number of fuel bundles	-	444								
Control rods										
Absorbing material	-	B ₄ C								
Number of CR	-	109								

The 1999/02/25 event





Event Description									
1	Turbine trip and bypass valves opening								
2	First 108% power level exceeding								
3	Stop Reducing pump velocity								
4	Second 108% power level exceeding								
5	Stop Reducing pump velocity								
6	Third 108% power level exceeding								
7	Stop Reducing pump velocity								
8	Operator Partially scrammed the reactor and reduced to the minimum the pump velocity.								
9	Reactor enter in the unstable region of the power/flow map								
10	The reactor scrammed because the power exceeded 132 %								

Code Used



RELAP5-3D© used for the Oskarshamn-2 benchmark



Reactor Coolant System modelling



RCS TH nodalization

- Number of Hydraulic volumes: 489 (core channels and bypass not included)
- 4 recirculation loops with external pumps (collapsed in one)
- 4 steam lines (collapsed in one)
- Passive Heat structures still not simulated







4 Different FA type of different fuel vendors present in the core







Type 4



Core modelling



444 Channels core nodalization

Έ				RE					1															
C			RE	RE	200	201	202	203	204	205	206	207	208	209	210	211	212	213	RE	RE				2
		RE	RE	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	RE	RE			3
	RE	RE	230	231	232	233	234	235	236	237	238	239	240	241	242	243	244	245	246	247	RE	RE		4
RE	RE	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	RE	RE	5
RE	268	269	270	271	272	273	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	RE	6
RE	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304	305	306	307	308	309	310	311	RE	7
RE	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	RE	8
RE	334	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	RE	9
RE	356	357	358	359	360	361	362	363	364	365	366	367	368	369	370	371	372	373	374	375	376	377	RE	10
RE	378	379	380	381	382	383	384	385	386	387	388	389	390	391	392	393	394	395	396	397	398	399	RE	11
RE	400	401	402	403	404	405	406	407	408	409	410	411	412	413	414	415	416	417	418	419	420	421	RE	12
RE	422	423	424	425	426	427	428	429	430	431	432	433	434	435	436	437	438	439	440	441	442	443	RE	13
RE	444	445	446	447	448	449	450	451	452	453	454	455	456	457	458	459	460	461	462	463	464	465	RE	14
RE	466	467	468	469	470	471	472	473	474	475	476	477	478	479	480	481	482	483	484	<u>485</u>	486	487	RE	15
RE	488	489	490	491	492	493	494	495	496	497	498	499	500	501	502	503	504	505	506	507	508	509	RE	16
RE	510	511	512	513	514	515	516	517	518	519	520	521	522	523	524	525	526	527	528	529	530	531	RE	17
RE	532	533	534	535	536	537	538	539	540	541	542	543	544	545	546	547	548	549	550	551	552	553	RE	18
RE	554	555	556	557	558	559	560	561	562	563	564	565	566	567	568	569	570	571	572	573	574	575	RE	19
RE	RE	576	577	578	579	580	581	582	583	584	585	586	587	588	589	590	591	592	593	594	595	RE	RE	20
_	RE	RE	596	597	598	599	600	601	602	603	604	605	606	607	608	609	610	611	612	613	RE	RE		21
	_	RE	RE	614	615	616	617	618	619	620	621	622	623	624	625	626	627	628	629	RE	RE			22
		-	RE	RE	630	631	632	633	634	635	636	637	638	639	640	641	642	643	RE	RE		۰.		23
			_	RE					24															
A	В	С	D	Е	F	G	н		J	к	L	м	N	0	Р	Q	R	s	т	U	v	w	х	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	

Core modelling



110 interconnected branches at the inlet/outlet of the core



				785	785	785	785	784	784	784	784	783	783	783	783	782	782	782	782					1
			RE	785	785	785	785	784	784	784	784	783	783	783	783	782	782	782	782	RE				2
		786	786	786	786	777	777	776	776	775	775	774	774	773	773	772	772	781	781	781	781			3
	RE	786	786	786	786	777	777	776	776	775	775	774	774	773	773	772	772	781	781	781	781	RE		4
787	787	787	787	771	771	770	770	769	769	768	768	767	767	766	766	765	765	764	764	780	780	780	780	5
787	787	787	787	771	771	770	770	769	769	768	768	767	767	766	766	765	765	764	764	780	780	780	780	6
788	788	763	763	762	762	761	761	760	760	759	759	758	758	757	757	756	756	755	755	754	754	779	779	7
788	788	763	763	762	762	761	761	760	760	759	759	758	758	757	757	756	756	755	755	754	754	779	779	8
788	788	753	753	752	752	751	751	750	750	749	749	748	748	747	747	746	746	745	745	744	744	779	779	9
788	788	753	753	752	752	751	751	750	750	749	749	748	748	747	747	746	746	745	745	744	744	779	779	10
789	789	743	743	742	742	741	741	740	740	739	739	738	738	737	737	736	736	735	735	734	734	778	778	11
789	789	743	743	742	742	741	741	740	740	739	739	738	738	737	737	736	736	735	735	734	734	778	778	12
789	789	733	733	732	732	731	731	730	730	729	729	728	728	727	727	726	726	725	725	724	724	778	778	13
789	789	733	733	732	732	731	731	730	730	729	729	728	728	727	727	726	726	725	725	724	724	778	778	14
790	790	723	723	722	722	721	721	720	720	719	719	718	718	717	717	716	716	715	715	714	714	799	799	15
790	790	723	723	722	722	721	721	720	720	719	719	718	718	717	717	716	716	715	715	714	714	799	799	16
790	790	713	713	712	712	711	711	710	710	709	709	708	708	707	707	706	706	705	705	704	704	799	799	17
790	790	713	713	712	712	711	711	710	710	709	709	708	708	707	707	706	706	705	705	704	704	799	799	18
791	791	791	791	703	703	702	702	701	701	700	700	699	699	698	698	697	697	696	696	798	798	798	798	19
791	791	791	791	703	703	702	702	701	701	700	700	699	699	698	698	697	697	696	696	798	798	798	798	20
189	RE	792	792	792	792	695	695	694	694	693	693	692	692	691	691	690	690	797	797	797	797	RE	178	21
189	189	792	792	792	792	695	695	694	694	693	693	692	692	691	691	690	690	797	797	797	797	178	178	22
189	189	133	RE	793	793	793	793	794	794	794	794	795	795	795	795	796	796	796	796	RE	124	178	178	23
190	190	123	123	793	793	793	793	794	794	794	794	795	795	795	795	796	796	796	796	114	114	199	199	24
A	В	С	D	E	F	G	н		J	к	L	м	N	0	Р	Q	R	S	т	U	V	w	X	16
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	17
190	190	113	113	112	112	111	111	110	110	109	109	108	108	107	107	106	106	105	105	104	104	199	199	18
191	191	191	191	103	103	102	102	101	101	100	100	99	99	98	98	97	97	96	96	198	198	198	198	19
191	191	191	191	103	103	102	102	101	101	100	100	99	99	98	98	97	97	96	96	198	198	198	198	20
_	RE	192	192	192	192	95	95	94	94	93	93	92	92	91	91	90	90	197	197	197	197	RE		21
	_	192	192	192	192	95	95	94	94	93	93	92	92	91	91	90	90	197	197	197	197			22
		_	RE	193	193	193	193	194	194	194	194	195	195	195	195	196	196	196	196	RE				23
				193	193	193	193	194	194	194	194	195	195	195	195	196	196	196	196					24
А	В	С	D	E	F	G	н	I	J	К	L	м	Ν	0	Ρ	Q	R	S	Т	U	V	w	Х	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	

Core TH & NK nodalization

- Core Axial meshing:
 - Uniform meshing for the active part 25 Hydraulic mesh + 25 Thermal mesh + 25 Neutronic mesh
 - 3 Hydraulic mesh + 2 Neutronic mesh for the bottom & top reflector
 - 1 Hydraulic meshes for FA inlet zone
- Core statistics
 - 444 independent TH channels +1 (Bypass)
 - 12876 Hydraulic volumes+ 29 (Bypass)
 - 14472 NK nodes (including Reflector)





Benchmark uncertainties ongoing definition



- Several Benchmark "Uncertainties" identified
 - Cross section library specifications (NEMTAB format still not available, CR specifications)
 - Channels pressure drop coefficients
 - Materials thermal capacity and conductivities
 - Configuration of the channel connection to the lower plenum
- Missing data replaced by engineering judgment and inhouse developed tools (e.g., CASMO Xsec interpolator)



NAME	u.d.m	NPP	NPP Code	RELAP5-3D	Rel. error
Reactor Power	MW	1798.6	1802	1798.6	IMPOSED
Steam Dome Pressure	MPa	6.93	7.00	6.94	0.12%
Core Inlet Pressure	MPa	N/A	7.166	7.095	-0.99%
Core Outlet Pressure	MPa	N/A	7.067	6.996	-1.00%
Core ΔP	kPa	N/A	98.8	98.5	-0.34%
Channel ΔP	kPa	N/A	46.0	50.8	10.36%
Orifice & Lwr plate ∆P	kPa	N/A	52.8	47.7	-9.66%
Core Average Void		N/A	0.42	0.44	4.19%
Core Average Fuel Temp	К	N/A	816.7	854.7	4.65%
Feed water Temperature	К	457.6	N/A	457.7	IMPOSED
Core Inlet Temperature	К	547.30	548.05	547.1	-0.03%
Steam Temperature	К	N/A	N/A	557.9	N/A
Pump Speed	Rad/s	N/A	N/A	99.78	N/A
Total Core Flow Rate	kg/s	5474.0	5515.9	5474.0	0.00%
Active Core Flow Rate	kg/s	N/A	4793.5	4759.7	-0.70%
Steam Flow Rate	kg/s	900.0	976.0	904.5	0.50%
Downcomer Water Level	m	N/A	N/A	8.4	N/A
K-eff	//	N/A	1.0026	1.0056	30 pcm

Steady state results



Mass Flow Rate, Pressure and Temperature convergence



Power Radial shape factor and relative error for all 444 FA









□ Mass flow rate and relative error for all 444 FA



Mass flow rate Error (%)





AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

Exit void fraction and P/G factor for all 444 FA

Exit void fraction



P/G Factor (MW/(kg/s))



Boundary conditions







Recirculation MFR, SD Pressure, SL MFR, Power Flow map





. Dev.



Total core Power



Average clad Temperature Vs. Hot Spot temperature







Animation



Sensitivity analysis results



\square +/- 10 % Heat Capacity of UO₂ and Clad



□ +/- 10 % GAP Conductance









Sensitivity analysis results



□ +/- 3 K feed water temperature



□ +/- 1 s CR insertion time









Notes for R5-3D developers



- Main issues during nodalization development/code run
 - Limitation on TH mapping did not allow to connect 1:1 the TH volumes & NK nodes (9999 zone figures available vs. 444x25=11100 requested) → some "homogenization" needed →Q: is it possible to increase the zone figures number in future releases?
 - Possibility to implement the large CASMO Xsec database (9999 compositions available) → conflicting with the input deck length → "Input too long" error message (R5v.3.0beta)
 - 3. Implementation of Xsec cross terms & "online" Xsec interpolation not possible

Conclusion & future steps



- ENEA is using R5-3D code as reference tool for NPP simulation
- Oskarshamn-2 BWR state-of-the-art model for RELAP5-3D© system code has been developed
 - detailed 3D neutronic coupled thermal-hydraulic model
 - developed for instability analyses → Oskarshamn-2 Feb.
 1999 event
- Steady state and on transient preliminary qualification achieved
 - Main «uncertainties» of the data set identified and their effect on simulation result assessed
- Future steps for the model qualification: performing blind calculations simulating the 1999 O-2 stability tests