RELAP5-3D Participation in CASL

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Outline

- CASL background
- What is LIME?
- Integration of RELAP5-3D into VERA
- Current status of RELAP5-3D in the CASL program
- Summary

Can an advanced "Virtual Reactor" be developed and applied to proactively address critical performance goals for nuclear power?

1

Reduce capital and operating costs per unit energy by:

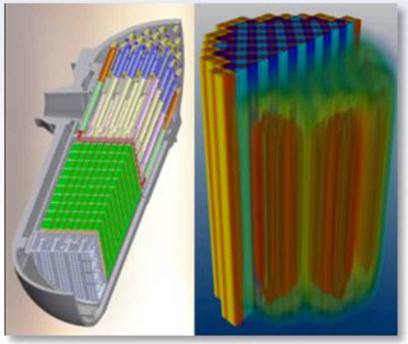
- Power uprates
- Lifetime extension

2

Reduce nuclear waste volume generated by enabling higher fuel burnups

3

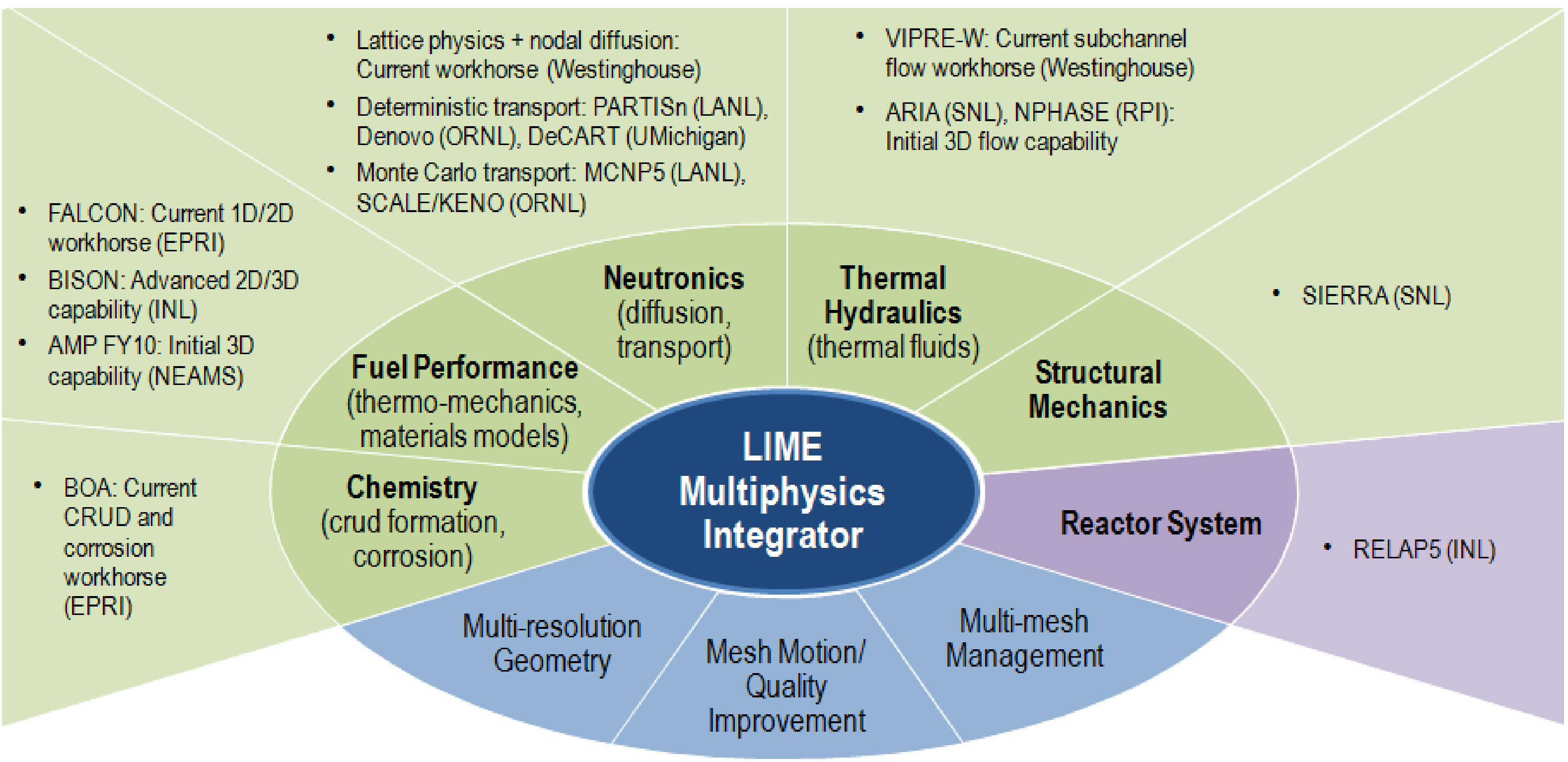
Enhance nuclear safety by enabling high-fidelity predictive capability for component and system performance from beginning of life through failure



CASL has selected key phenomena limiting reactor performance selected for challenge problems

	Power uprate	High burnup	Life extension
Operational			
CRUD-induced power shift (CIPS)	×	×	
CRUD-induced localized corrosion (CILC)	×	×	
Grid-to-rod fretting failure (GTRF)		×	
Pellet-clad interaction (PCI)	×	×	
Fuel assembly distortion (FAD)	×	×	
Safety			
Departure from nucleate boiling (DNB)	×		
Cladding integrity during loss of coolant accidents (LOCA)	×	×	
Cladding integrity during reactivity insertion accidents (RIA)	×	×	
Reactor vessel integrity	×		×
Reactor internals integrity	×		×

The CASL Virtual Reactor (VERA) builds on a foundation of mature, validated, and widely used software



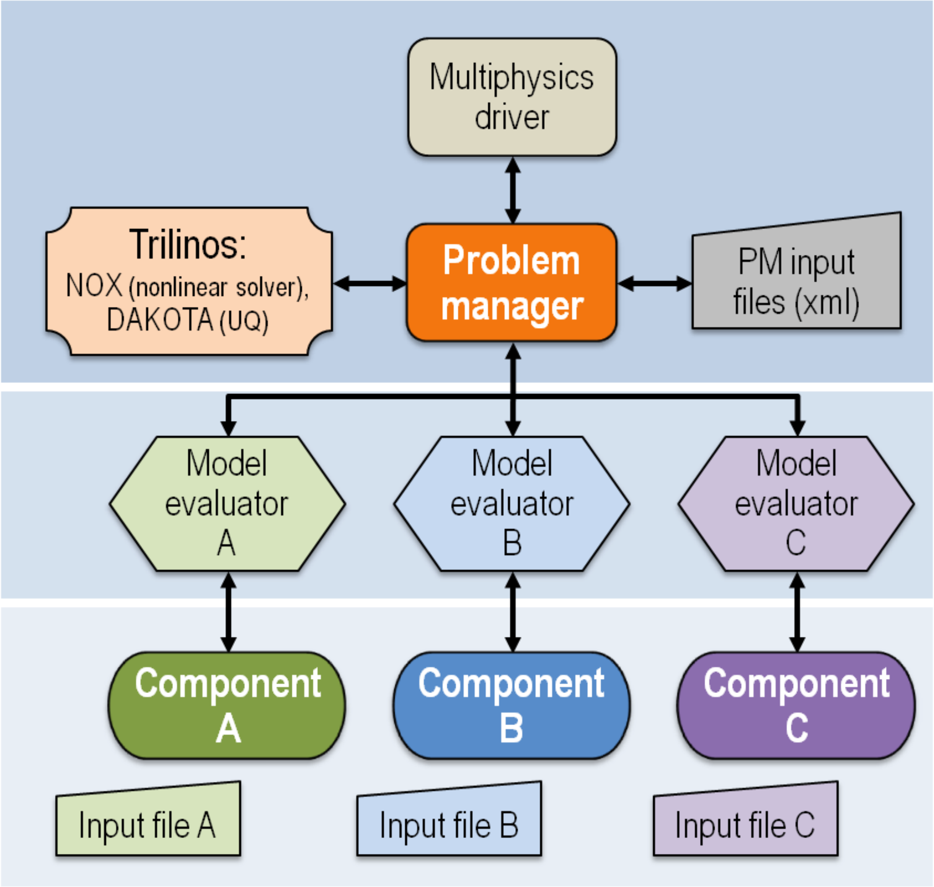
What is LIME?

- An acronym for Lightweight Integrating Multi-physics Environment for coupling codes
- A tool for creating multi-physics simulation code(s) that is particularly useful when computer codes are currently available to solve different parts of a multi-physics problem
- One part of the larger VERA framework being developed in CASL

Important characteristics of LIME

- LIME is designed to:
  - Enable separate physics codes (“new” and “old”) to be combined into a robust and efficient fully-coupled multi-physics simulation capability
  - Allow composition of both controlled and open-source components, enabling protection of export-controlled or proprietary code while still allowing distribution of the core system and open components
- LIME is not limited to:
  - Codes written in one particular language
  - A particular numerical discretization approach (e.g., finite element)
- LIME is not “plug and play”:
  - Requires revisions/modifications to most stand-alone physics codes
  - Requires the creation of customized “model evaluators”

Key components of a simple generic application created using LIME



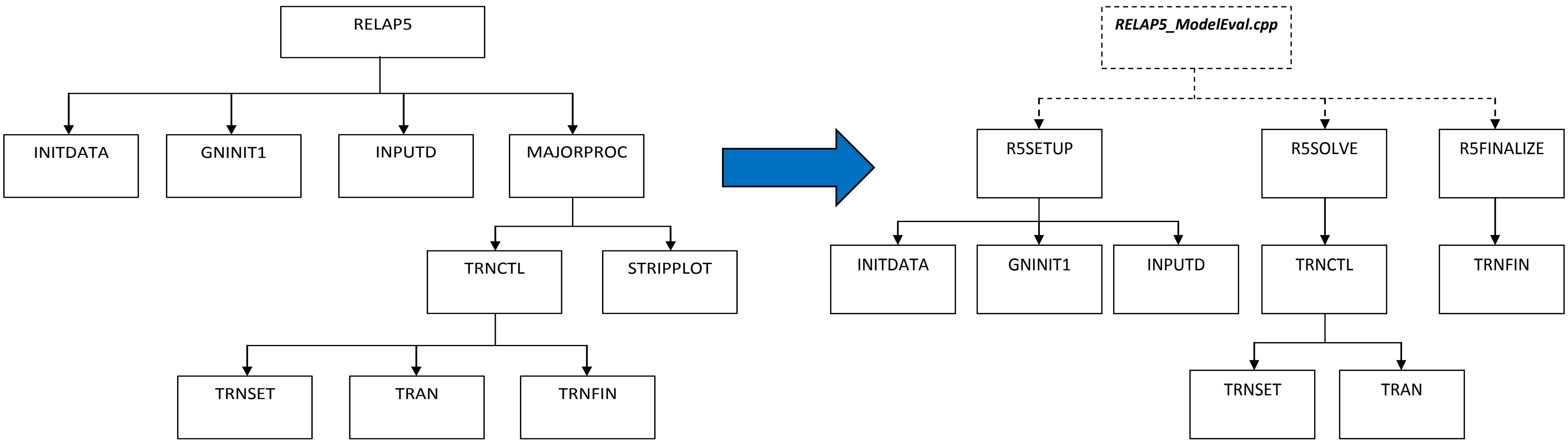
Revisions and modifications that may be required of a physics code

- Console I/O must be redirected (no pause statements or read/write to standard streams)
- Each code must be wrapped so the multi-physics driver can link to it (i.e., like a library)
- Each code must be organized into several key parts that can be called independently
  - Initialization: *read inputs, allocate memory…*
  - Solve: *compute solution for a given time step and state*
  - Advance: *copy converged state and prepare for next step*

Status of LIME

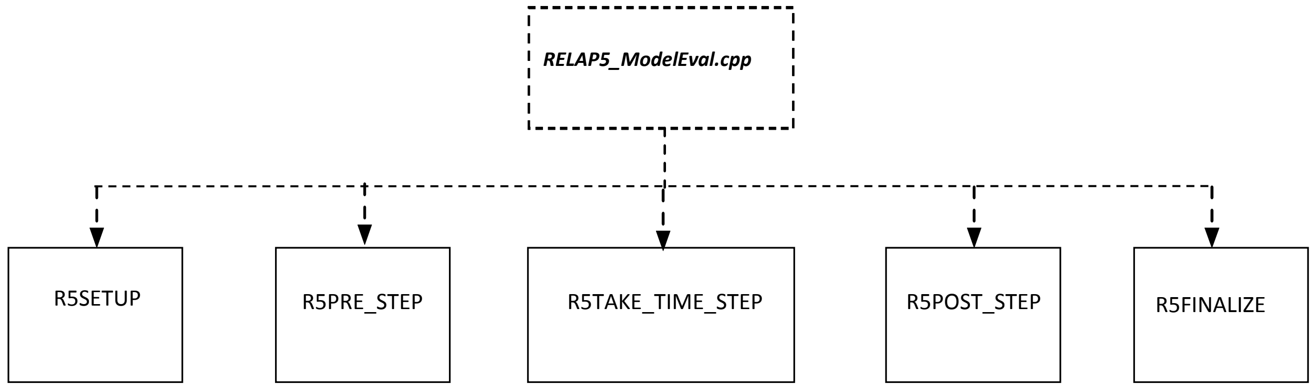
- Theory manual: Sandia report SAND2011-2195
- User manual: Sandia report SAND2011-8524
- LIME 1.0 (source and documentation) on sourceforge.net

Refactorization of stand-alone RELAP5-3D



Improvements to Model Evaluator

- Modifications needed to move from stand-alone to a coupled capability
- Further refactoring of RELAP5 to allow LIME to control time steps
  - R5solve split into three new routines
  - Corresponding function calls added to model evaluator
- LIME program manager needed to be modified to handle re-negotiation of time step size after RELAP5-3D cuts (or increases) it



LIME time step control

LIME Problem Manager	RELAP5 Model Evaluator
`time_step = determine_time_step()`	`get_time_step()` `return caslmod_mp_requested_dt`
`set_time_step()`	`set_time_step(double dt)` `caslmod_mp_lime_dt_ = dt`

`solve_nonlinear(test_time_step)`	`solve_standalone(double & dt)`
	`RELAP5_R5TAKE_TIME_STEP_F77 ()`
	`dt = caslmod_mp_lime_dt`

`has_time_step_changed(test_time_step,time_step)`	
`current_time += time_step`	
`update_time()`	`update_time()`

RELAP5_ModelEval.cpp (1)

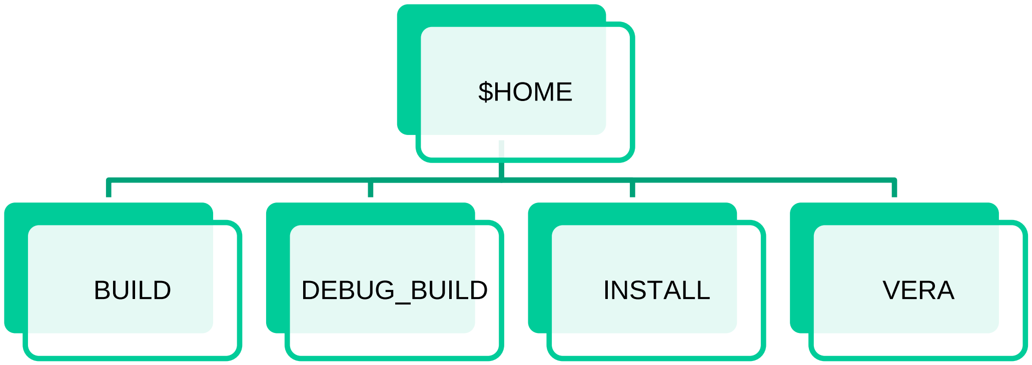
```
//---------------------- constructor ----------------------------------------

RELAP5_ModelEval::RELAP5_ModelEval(const LIME::Problem_Manager & pm,
                                   const string & name,
                                   Epetra_Comm& relap5_sub_comm,
                                   const std::string& input_file,
                                   const std::string& output_file,
                                   const std::string& restart_file) :
  problem_manager_api(pm),
  m_my_name(name),
  timer(0),
  m_input_file(input_file),
  m_output_file(output_file),
  m_restart_file(restart_file)
{
  RELAP5_R5SETUP_F77(&input_file[0],
                     &output_file[0],
                     &restart_file[0],
                      input_file.length(),
                      output_file.length(),
                      restart_file.length());
  RELAP5_R5PRE_STEP_F77 ();
}
```

RELAP5_ModelEval.cpp (2)

```
//---------------------- destructor -----------------------------------------

RELAP5_ModelEval::~RELAP5_ModelEval()
{
  RELAP5_R5FINALIZE_F77 ();
}

//----------------------- solve_standalone -----------------------------------

bool RELAP5_ModelEval::solve_standalone(double & dt)
{
  RELAP5_R5TAKE_TIME_STEP_F77 ();
  dt = caslmod_mp_lime_dt_;
  return (true);
}

//----------------------- get_time_step --------------------------------------

double RELAP5_ModelEval::get_time_step() const
{
  return caslmod_mp_requested_dt_;
}
```

Conversion of RELAP5-3D build system

- TriBITS (VERA build system) uses CMake
  - Cross-platform, open-source build system
  - Uses compiler-independent configuration files to generate native makefiles
- RELAP5-3D build scripts replaced by CMake files
  - Easier integration with TriBITS
  - Necessary for inclusion in CASL automated software testing
  - Allows out-of-tree builds

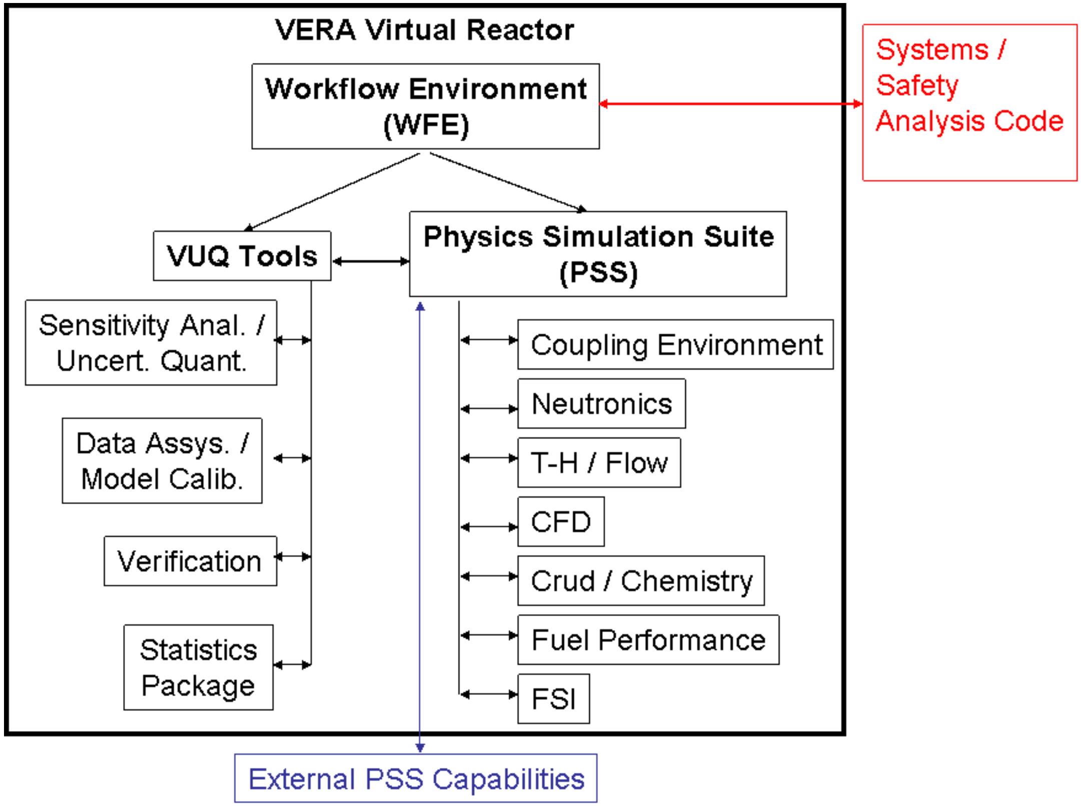


Addition of RELAP5-3D to CASL testing

- VERA software packages stored in CASL repository under Git revision control
- Automated testing checks out appropriate source, performs builds, and runs tests at various frequencies
  - Check in test script: manual process to do basic testing and determine if it is safe to commit/push changes
  - Continuous integration: continuous loop that runs tests when global repository changes are detected
  - Nightly regression testing: a range of VERA configurations are built and tested with different compilers (e.g., gnu and Intel)
- Emails sent to relevant developers when failures are detected

Role of RELAP5-3D in CASL

- VERA is being developed to address challenge problems
- Initial emphasis is on core physics/TH and crud deposition



Role of RELAP5-3D in CASL

- VERA Requirements Document describes technical abilities VERA should provide
  - *capability to integrate* systems analysis codes (e.g. RETRAN, RELAP5, RELAP7) to support performance of nuclear safety analyses and analysis of plant accidents and transients
    - RIA
    - LOCA
    - Non-LOCA transients and accidents
  - These capabilities to be added in stages as relevant challenge problems are addressed
- RELAP5-3D is currently on hold

Future development issues

- RELAP5-3D can’t be distributed with VERA
  - Export control
  - License issues
- Will CASL version be synced with INL development version? If so, how?
  - It must be, if RELAP5-3D is supplied by licensees
  - RELAP5-3D not maintained in an accessible repository
  - CASL costs associated with merging new RELAP5-3D version
  - INL costs associated with ongoing maintenance of CASL mods
- Software use agreement applies to version 3.0.0
- INL would have to maintain a VERA environment for QA testing
- What about training, support, etc.?

Summary

- Initial VERA integration completed early this year
- CASL continues to address current challenge problems
- Safety analysis challenge problems not yet defined
- Further development on hold for FY13
- Unanswered questions about ongoing/future maintenance issues