

## Sodium Spray Fire Simulations using CONTAIN-LMR

Andrew Jordan Clark, Matthew Roy Denman

*Sandia National Laboratories: P.O. Box 5800, Albuquerque, NM 87185, USA, Andrew.Clark2@sandia.gov*

### INTRODUCTION

License applications for sodium fast reactors will include sodium fire analysis and subsequent mitigation strategies. Sodium leaks or ruptures from piping and support systems can lead to significant fires due to the reactive nature of sodium with air and water. Understanding the behavior of sodium fires is crucial for modeling and predicting accidents in sodium fast reactors.

This paper describes the initial results of a control volume code, CONTAIN-LMR (CLMR), modeling effort for a sodium spray fire experiment conducted at Sandia National Laboratories (SNL) in Albuquerque, New Mexico in 2010. Additional sodium spray and pool fire tests were conducted at SNL in 2009 and 2010 and will be compared to CLMR results in future papers. The purpose of this analysis was extract information from the evolution of the SNL tests to better understand how to use CLMR in future sodium fire analysis. Thus the following CLMR simulations were not completely the result of blind benchmarking study.

### SNL SODIUM SPRAY FIRE EXPERIMENTS

A series of sodium spray and pool fire experiments were performed at Sandia National Laboratories (SNL) at the Nuclear Energy Work Complex (NEWC) in Albuquerque, NM in 2009 and 2010 (Olivier 2010). Sodium spray fire experiments were conducted both outdoors and in-vessel. Two in-vessel experiments were conducted within the Surtsey vessel located at the NEWC, as seen in Fig. 1. The primary difference between the two in-vessel experiments (referred to as T3 and T4) is the temperature of the sodium that was sprayed into the vessel. Initial sodium temperatures were 200°C and 500°C for experiments T3 and T4, respectively. All other conditions remained the same, such as nozzle type, height of spray, flow rate, etc. Experiment T3 ran to completion without failure, but the T4 experiment experienced an instrumentation port failure during the experiment. Only T3 experimental and modeling results are presented in this paper.

#### Surtsey T3 Experiment

The Surtsey vessel (Fig. 1) has a volume of about 100 m<sup>3</sup>. Sodium was loaded into a melt generator that stands outside of the vessel. The melt generator was pressurized to about 2 MPa and sodium was melted to 200°C. Once the sodium was completely melted, a valve

was opened to allow sodium to flow from the melt generator, through a series of pipes, and then sprayed into the vessel through an H15 nozzle. Experimental summary for the T3 experiment is provided in Table I. Temperature, pressure, and heat flux data was recorded for the spray fire experiments. The modeling efforts focused primarily on temperature and pressure evolution through the duration of the experiment. Fig. 2 provides an image of the sodium spray fire during the first couple of seconds.



Fig. 1. Surtsey vessel at NEWC located at SNL in Albuquerque, NM.

Table I. Summary of T3 sodium spray fire experiment.

Sodium Mass Injected	20 kg
Sodium Mass Flowrate	1 kg/s
Spray Height	5.3 m
Initial Sodium Temperature	200°C
Surtsey Vessel Volume	100 m <sup>3</sup>
Surtsey Vessel Thickness	1 cm

### SODIUM SPRAY FIRE MODELING

The T3 sodium spray fire was modeled using CLMR (Murata 89, Murata 93). CLMR is a keyword driven code that requires specific physic packages be specified, or else the physics associated with that package will not

contribute to the results. Sodium spray fire phenomenological models in CLMR are adopted from the NACOM code (Tsai 1980). In addition to the parameters listed in Table I, the duration of the spray and the droplet diameter needed to be specified. Based on the mass flow rate and amount of sodium injected, the duration of the spray is about 20 seconds. Olivier (2010) reported a mean diameter of about 3-5 mm; but based on initial simulations the diameter is likely to be less than 3 mm.



Fig. 2. T3 sodium spray fire during the first couple of seconds.

## RESULTS

The first CLMR run with the input parameters described above is shown in Fig. 3 and Fig. 4. As seen in Fig. 3 and Fig. 4, the simulation results match fairly well with experimental data within the first 20 seconds. However, the temperature and pressure predicted by CLMR sharply decrease to the initial in-vessel conditions after all the sodium has been sprayed into the vessel.

Two other notes about the experimental data should be made. First, there are two obvious peaks in the experimental data during the first 20 seconds. It is believed that these two peaks are caused by two separate ignition events that occur during the spray. Two distinct yellow “flashes” in video recordings of the spray supports this belief. Coincidentally, the time at which these two

“flashes” occur also align with the experimental data (about 3 and 10 seconds).

Second, based on experimental data, it appears that the duration of the spray was about 14 seconds rather than 20 seconds. However, this results presented in this paper assumes a 20 second duration spray.

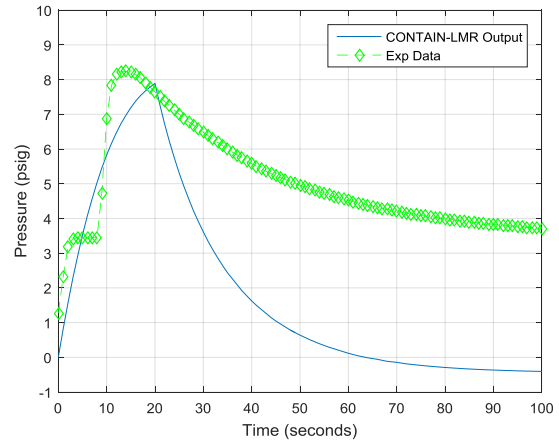


Fig. 3. Experimental and CLMR pressure results.

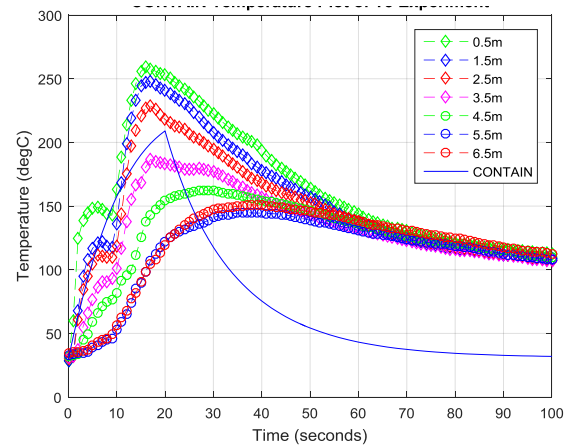


Fig. 4. Experimental and CLMR temperature results.

## Sodium Pool Fire Activation

Depending on the sodium droplet size specified in the input, it is possible that sodium droplets will not completely burn before they hit the ground. For example, when the spray droplet diameter is set to 2.0 mm and 20 kg is sprayed into the vessel in CLMR, 6.2 kg burns in the air and 13.8 kg goes unburned and collects in a pool on the ground. The results presented in Fig. 3 and Fig. 4 did not consider the sodium that is added to the pool and subsequent burning that occurs.

Because CLMR is a keyword driven code, if a specific keyword is not explicitly activated the physics associated with this keyword do not contribute to the final results. For the simulations in Fig. 3 and Fig. 4, the keyword for the sodium pool fire was not activated. Thus,

the previous results do not consider sodium pool burning. Shown in Fig. 5 are the results for when the sodium pool fire keyword is activated. This keyword has four ratio values as inputs (f1, f2, f3 and f3); the default values used by CLMR were not adjusted. These ratios are described in CONTAIN-LMR User Manual (Murata 93).

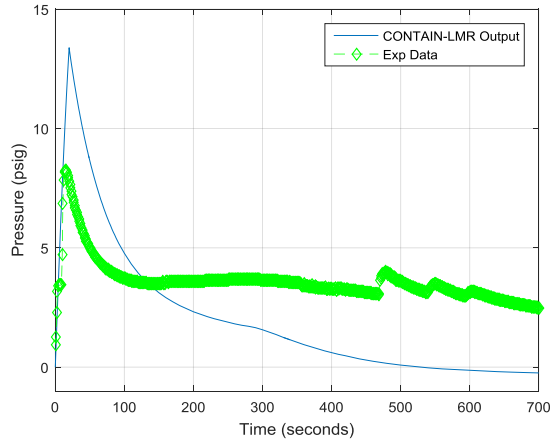


Fig. 5. Surtsey vessel pressure with CLMR sodium pool fire physics activated.

The activation of the sodium pool fire has a noticeable effect on the pressure evolution in the Surtsey vessel. Pressure drop is more relaxed over time because the sodium burning in the pool adds heat to the vessel. Compared to Fig. 3, the CLMR pressure trend in Fig. 5 matches more closely with the observed pressure trend. At about 300 seconds, the sodium in the pool essentially stops burning and the pressure drops to a steady-state pressure of -0.3 psig at about 800 seconds. The sodium likely stopped burning due to an internal sodium oxide crust formation model within CLMR. These models seem to be non-conservative when compared to the long term experimental T3 results.

### CLMR and Experimental Data Alignment

Sensitivity studies were conducted to match the experimental data by adjusting selected variables. These changes are given in Table II and the results are shown in Fig. 6. First, two variables were adjusted to better align with the data: the atmospheric temperature and the sodium droplet diameter (Model Run 1). As seen in Fig. 6, these changes reduced the pressure peak toward the experimental data and the cooling rate relaxed. Overall, these changes improve the agreement between the computational and experimental data trends.

Heat transfer mechanisms in CLMR are largely responsible for the discrepancy between simulation and experimental data. The second ratio, f2, in the pool fire keyword is the fraction of reaction heat that is applied to the pool. The complement of this fraction (1 - f2) is

applied to the atmosphere. Thus, the sensitivity of the simulation results to this variable was investigated in Model Runs 2 and 3. It is noted in the CLMR manual that the default value of 1 assumes that the user models heat transfer through other modeling keywords.

Table II. Sensitivity of CLMR results to selected variables.

Model Run	Variable	Old Value	New Value
1	Atmos, T <sub>ini</sub>	303.15 K	288.15 K
	Sprafire, dme	2.00 mm	2.45 mm
2	Atmos, T <sub>ini</sub>	303.15 K	288.15 K
	Sprafire, dme	2.00 mm	2.45 mm
	Poolfire, ratios (f1, f2, f3, f4)	0.5, 1.0, 1.0, 0.0	0.5, 0.9, 1.0, 0.0
3	Atmos, T <sub>ini</sub>	303.15 K	288.15 K
	Sprafire, dme	2.00 mm	2.45 mm
	Poolfire, ratios (f1, f2, f3, f4)	0.5, 1.0, 1.0, 0.0	0.5, 0.5, 1.0, 0.0

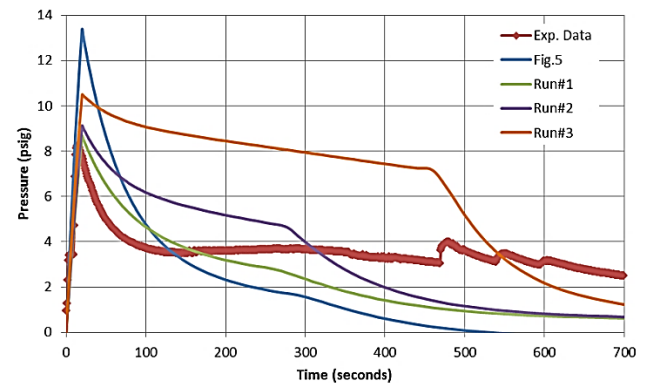


Fig. 6. CLMR outputs based on model runs in Table II.

The temperature plot for Model Run #1 is shown in Fig. 7. Additionally, the effect of the “poolfire” keyword activation was also observed for this run as seen in Fig. 8.

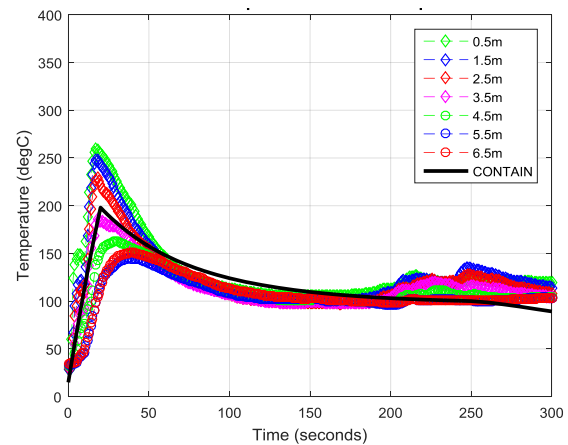


Fig. 7. Model Run #1 temperature results compared to experimental data.

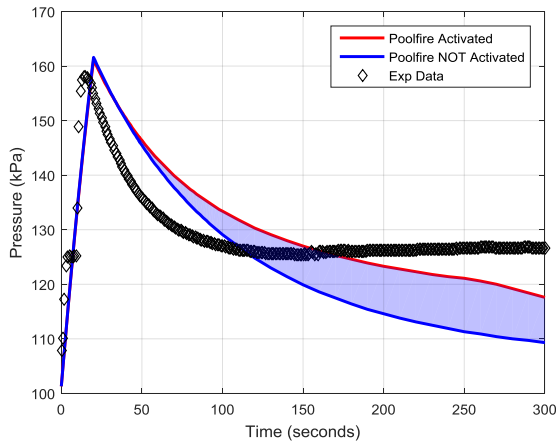


Fig. 8. Model Run #1 with "poolfire" keyword activated and not activated.

### Sodium Droplet Diameter Sensitivity

In addition to the  $f_2$  ratio, the results are also sensitive to the specified sodium droplet diameter. This sensitivity is shown in Fig. 9 for droplet diameters of 1 mm, 2 mm, and 3 mm. In Model Run #1, the droplet diameter was adjusted until the simulated pressure peak aligned with the experimental pressure peak. However, this adjustment does not necessarily determine the experimental sodium droplet diameter in the T3 experiment.

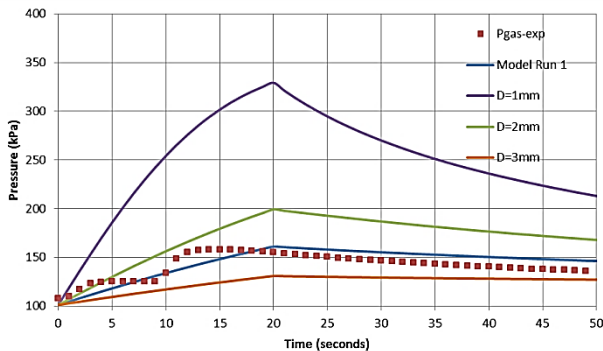


Fig. 9. CLMR result sensitivities to sodium droplet diameter.

### CONCLUSION

These results show that the Model Run #1 simulation of the T3 sodium spray fire using CLMR follows the same general trend seen for the experimental data. The CLMR results are highly sensitive to the  $f_2$  ratio and sodium droplet diameter. The experimental sodium droplet diameter remains unknown. Water-sodium droplet correlations have been investigated, but these correlations do not match with the CLMR results and have not been included here. With regards to heat transfer mechanisms,

it is not well understood how the so-called " $f_2$  ratio" used in pool fire physics affects or competes with other defined heat transfer models. Further investigation is needed to better understand how this ratio and the other heat transfer mechanisms compete with one another.

### ACKNOWLEDGEMENTS

This work was supported by the Advanced Reactor Technologies Program at the Department of Energy. Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the US Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

### REFERENCES

- K.K. Murata, et al., "User's Manual for CONTAIN 1.1: A Computer Code for Severe Nuclear Reactor Accident Containment Analysis", SAND87-2309, Sandia National Laboratories, Albuquerque, NM, (1989).
- K.K. Murata, et al., "CONTAIN LMR/1B-Mod. 1, A Computer Code for Containment Analysis of Accidents in Liquid-Metal-Cooled Nuclear Reactors", SAND91-1490, Sandia National Laboratories, Albuquerque, NM, (1993).
- T.J. Olivier, et al., "Metal Fires and Their Implications for Advance Reactors Part 3: Experimental and Modeling Results", SAND2010-7113, Sandia National Laboratories, Albuquerque, NM, (2010).
- S.S. Tsai, "The NACOM Code for Analysis of Postulated Sodium Spray Fires in LMFBRs," NUREG/CR-1405, BNL-NUREG-51180, Brookhaven National Laboratory, Upton, NY, (1980).