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BLC-CNWG
Sandia National Laboratories
Sandia Research and Development on Sodium-Concrete Reaction
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ENERGY
NNSA

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Outline

- Experimental works in 1980s
  - Laboratory-scale experiments [NUREG/CR-3401, SAND83-1502]
  - Intermediate-scale experiments [NUREG/CR-3288, SAND83-1064]
- Sodium-Limestone Concrete Ablation Model (SLAM) [NUREG/CR-3379, SAND83-7114]
- Future implementation of SLAM into MELCOR

According to SAND83-1502, the reaction mechanisms for SCR on basalt and magnetite concretes were understood. And for carbonate concretes, such as limestones, the mechanisms were not well understood.

We will also examine other types of concretes, even through the SLAM is ready for us to implement into MELCOR.

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Purpose of Sandia's Sodium Concrete Reaction (SCR) Experiments

- Many SCR tests were done before Sandia's tests – to study the mechanism on reactions to basalt, magnetite and carbonate concretes
- Reactions between sodium and carbonate concretes, particularly the mechanisms not understood. Clinch River LMFBR used carbonate concretes
- The intermediate tests were done as a companion tests to those tests done at HEDL to allow comparisons between two laboratories.
- Due to uncertainty with the larger tests, laboratory-scale tests were conducted to better characterize the reaction (or interaction) between sodium and concrete (carbonate/limestone).
- To develop SCR model, such as Sodium-limestone ablation model (SLAM) from these Sandia tests.

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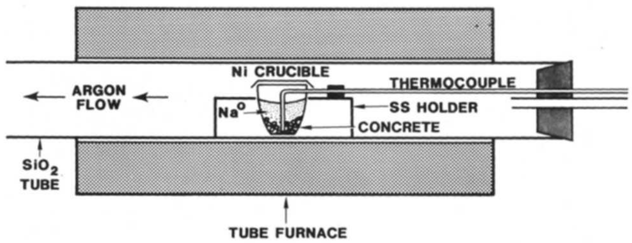
Laboratory-Scale Experiments at Sandia



- Horizontal resistance tube furnace (7.5 cm ID x 80 cm Long)
- Silica glass tube liner (6.0 cm ID x 122 cm Long)
- Argon flow at 100±5 cc/min
- A single sheathed chromel-alumel TC

Material	**Limestone***	**Dolostone****
	Weight Percent	
Aggregate	79.7	78.8
Cement Type II	12.0	10.3
Water	6.3	7.5
Flyash	2.0	3.4
Admixture***	<0.1	<0.1

***70% calcite and 30% dolomite**
****85% dolomite and 15% calcite**
*****Includes both air-entraining and water reducing agents**

Placing solid Na and concrete/aggregate in nickel crucible at room temp. Placing the crucible in a horizontal tube furnace continuously purged with an inert gas (N2 or Ar). Test temp is 600 C in pre-heat or continuous heating. A TC is placed in crucible as shown. For most samples, a sharp inflection in the time-temp plot is the indication of the exothermic reaction. The test lasts about 20 minutes before quenching by moving the sample out of the furnace and cool below its solidification of 97.5 C. Each test lasts about 40 minutes from startup of the furnace and then 25 minutes for thermal and chemical equilibration. The difference between preliminary and control tests is the size of the concrete solids – preliminary is larger than control as shown.

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Table 5. Controlled Sodium-Carbonate Concrete Test Conditions and Results

Test ID	Reactants* (g)	Sodium/Concrete Ratio	Threshold Temperature (°C)	Relative Heat**
NACO00	20.0 Na	-	-	-
NACO01	17.5 Na + 2.5 Ls Conc	7.0	595±10	4.8
NACO02	14.9 Na + 5.1 Ls Conc	2.9	565±10	5.9
NACO03	10.0 Na + 10.0 Ls Conc	1.0	580±10	7.5
NACO04	4.6 Na + 15.6 Ls Conc	0.3	560±10	6.2
NACO05	5.0 Na + 15.0 Ls Conc	0.3	595±10	nm
NACO06	2.5 Na + 17.5 Ls Conc	0.1	570±10	3.5
NACO07	10.0 Na + 5.0 Ls Conc + 5.0 NaOH	-	605±10	6.0
NACO08	5.1 Na + (5.0 NaOH + 10.0 Ls Conc)#	-	525±10	5.2
NACO09	15.0 Na + 5.1 Cem	-	540±20	4.9
NACO10	15.0 Na + 5.0 Ls Agg	-	575±10	4.6
NACO11	15.0 Na + 5.1 Ls Agg(f)"	-	575±10	4.9
NACO12	14.9 Na + 5.0 Ls Conc+	3.0	540±10	5.0
NACO13	15.0 Na + 5.0 Cem+	-	515±10	1.8
NACO14	10.3 Na + 10.2 Dl Conc	1.0	585±20'	8.4
NACO15	10.0 Na + 10.0 Dl Agg	-	565±15	5.7
NACO16	10.0 Na + 10.0 Dl Agg(f)"	-	575±10	3.5
NACO17	10.2 Na + 10.0 Dl Conc+	1.0	530±10	5.8
NACO18	15.0 Na + 5.0 CC##	-	545±10	5.9
NACO19	20.0 Na	-	-	-
NACO20	10.3 Na	-	-	-
NACO21	30.5 Na	-	-	-

* Symbols: Na=metallic sodium; NaOH=sodium hydroxide; Ls=limestone; Dl=dolostone; Conc=concrete; Cem=Portland type II cement; Agg=aggregate; CC=calcium carbonate; nm=not measured.

** Arbitrary units of heat per gram mass of concrete or concrete component

Coated with sodium hydroxide at 350°C and then cooled to 30°C before addition of sodium.

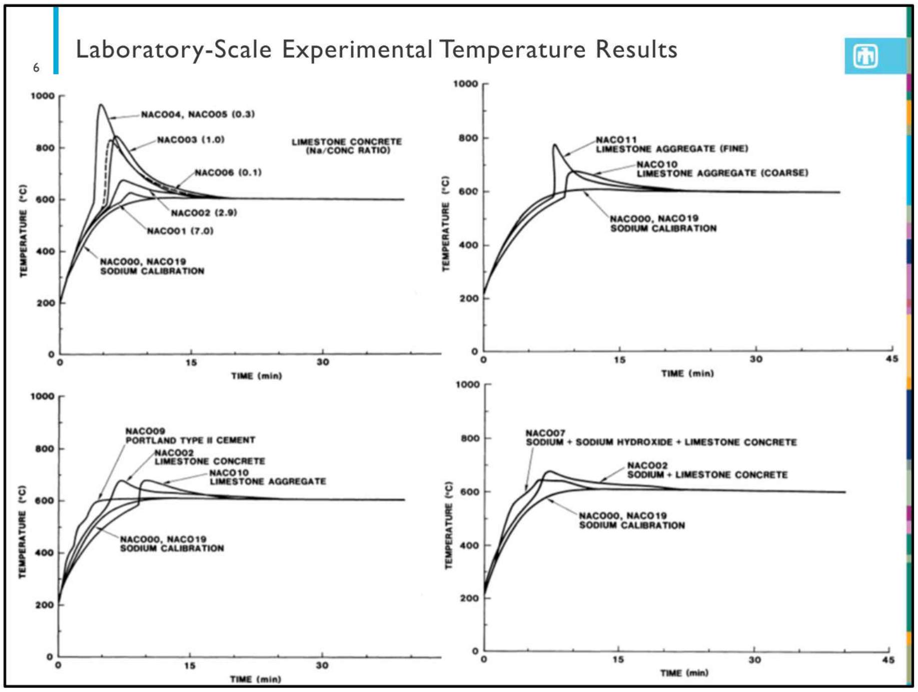
" Fragment size is between 0.25 and 0.42 mm.

+ Heated at 670°C for 2 hours; x-ray analysis indicates no decarbonation.

' Slow and gradual exothermic reaction.

Fine grained (<3.0 μm) reagent grade $CaCO_3$.

Try to maintain Na + test article to 20 grams
Test article is 3.35 to 4.75 mm concrete fragment

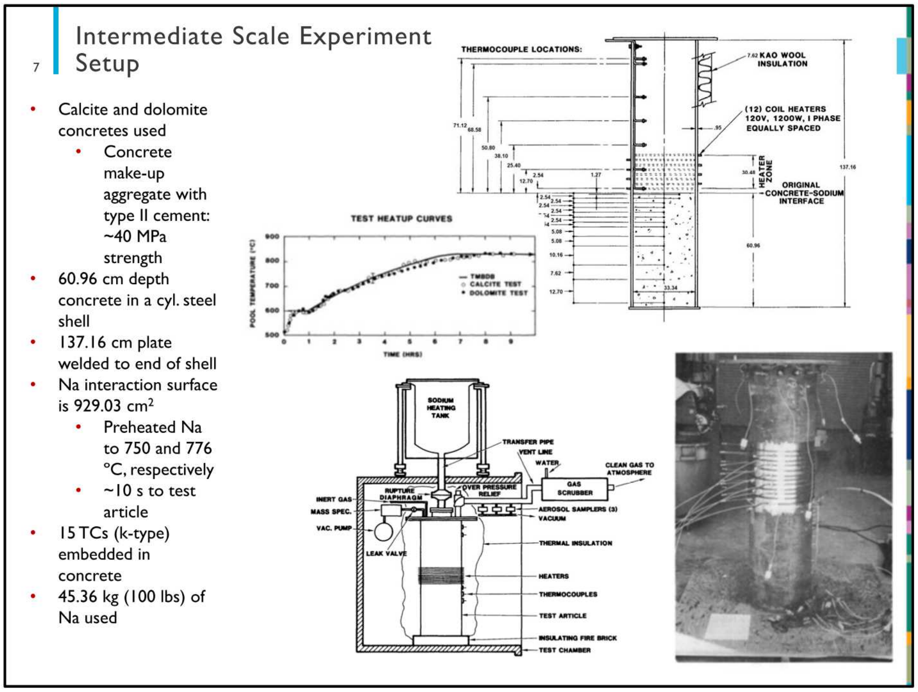


Upper left (fig 2) shows the effect of the Na/CONC ratio which are expected. The higher the ratio, the lower temperatures may be resulted. The peak temperature of these exotherms increase with decreasing sodium/concrete ratios until a maximum is reached at a ratio of about 0.3. However, the amount of heat produced per unit mass of solid reactant reaches
a maximum at a sodium/concrete ratio of 1.0 (see table 5). the time delay before onset of the exothermic reaction decreases with decreasing sodium/concrete ratios,
while their heating rates increase

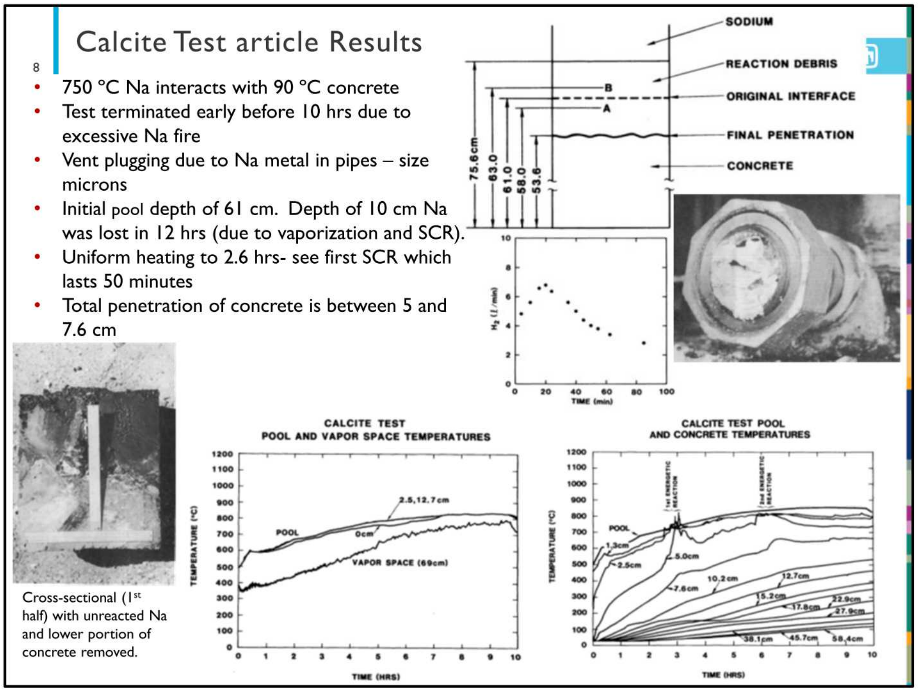
Upper right (fig 4) shows the effect of the coarse versus fine aggregate, as expected the fine aggregate will react with sodium that releases heat faster than the coarse aggregate.

Lower left (fig 3) shows the effect of the concrete types – Portland (without aggregate), concrete and aggregate.

Lower right (fig. 6) shows NAC007 with addition of NaOH pellets, which did not affect the heat amount produced, but did broaden the exotherm, and lower the peak temp.



An Ar gas purge of the test article 5 hours before each test at 2 liters/min. These tests provide the penetration depth of the reactions.



Na fire resulting from a Na leak because of the plugging. Interaction with concrete and vaporization account for the sodium loss. Cooling starts at about 10 hrs.

Dolomite Test Article Results

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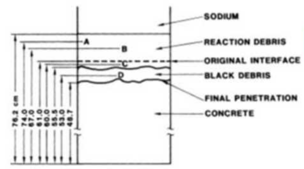
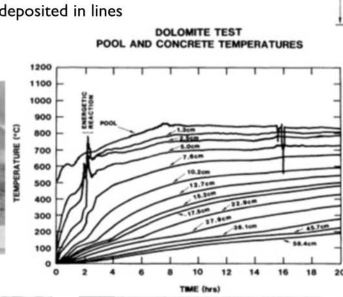
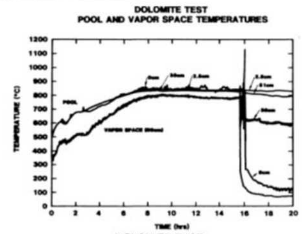
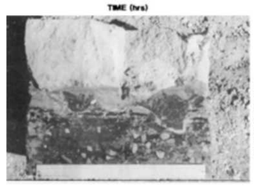
- Vent line was re-done to avoid plug
- Test went out to 20 hrs.
- Similar to the calcite test, there were 2 reaction temp. peaks.
- Na vapor aerosol deposited in lines



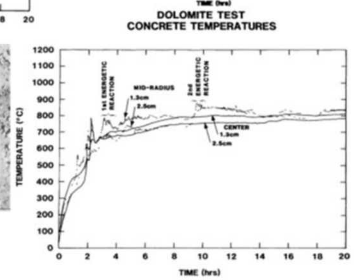




Higher magnification view of reaction zone



X-section, excess unreacted Na, bottom portion of concrete out



Test Results and Conclusions on Intermediate-Scale

- Na/concrete reaction zones
  - Calcite well demarcated boundary between completely reacted and unreacted concretes
  - Dolomite a thick, diffuse layer of partially decomposed concrete and reaction debris separating concrete regions – due to dolomite decomposition temperature
- Major species: NaOH, Na_2CO_3, CaO and MgO
  - Most important reaction in both concrete is Na and H_2O with limestone to form Na_2CO_3, H_2 and oxides, including free C.
- Note only 1 test each of two concretes – results may not be conclusive.

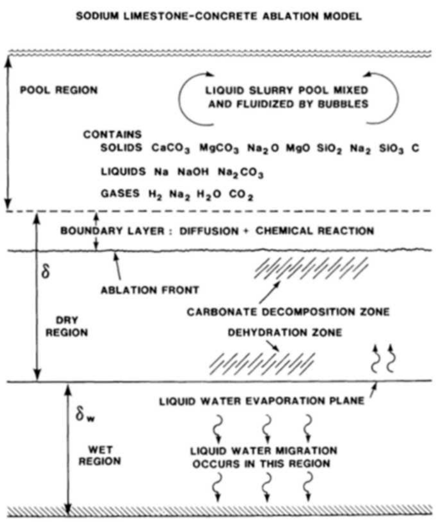
Summary of Calcite and Dolomite Test Results

	Calcite	Dolomite
Test Date	08/19/82	10/13/82
Test Temperature (°C)	830	830
Sodium Used (kg)	45.5	45.5
Test Length (hr)	10	20
Sodium Preheat Temperature (°C)	750	750
Minimum Quench Temperature (°C)	510	510
Maximum Concrete Temperature (°C) which occurred at (hr)	830 2.6	790 2.2
Penetration (cm)*	7.4 ± 5.0	5.5 ± 2.9 12.3 ± 2.9**
Maximum Penetration Rate by thermocouple indications (mm/min)	1.7	1.4

* at 95% confidence level

** Measured at black debris/unreacted concrete interface.

SLAM Model



$H_2O + Na \rightarrow NaOH + \frac{1}{2}H_2$

$CO_2 + 2\,Na \rightarrow 4\,Na_2O + C$

$3\,CaCO_3 + 4\,Na \rightarrow 2\,Na_2CO_3 + 3\,CaO + C$

$3\,MgCO_3 + 4\,Na \rightarrow 2\,Na_2CO_3 + 3\,MgO + C$

$2\,NaOH + CaCO_3 \rightarrow CaO + H_2O + Na_2CO_3$

$2\,NaOH + SiO_3 \rightarrow H_2O + Na_2SiCO_3$

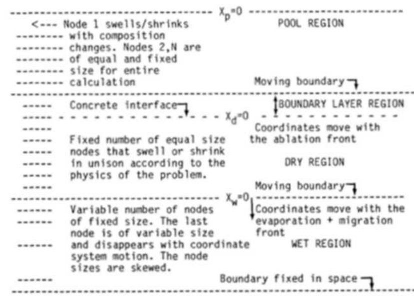
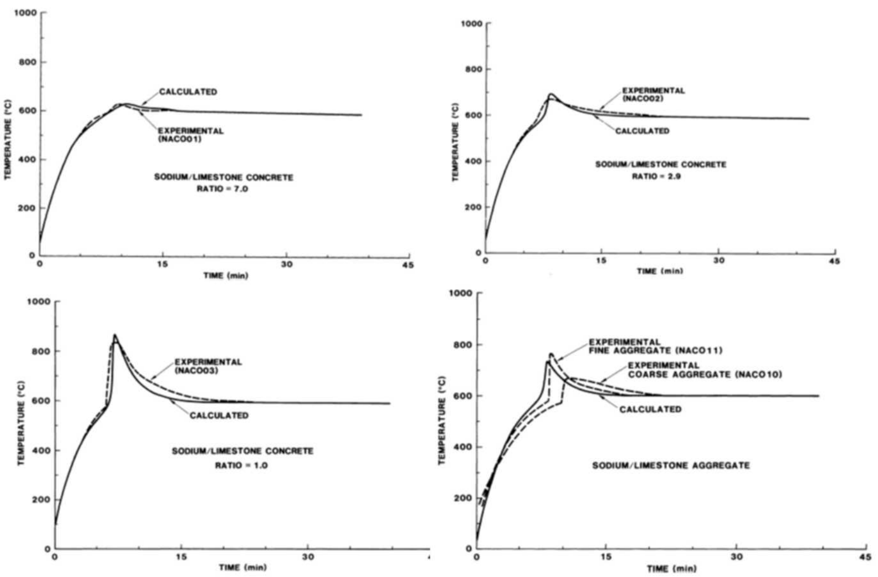


Figure 2. The SLAM Coordinate Systems
Subscripts p, d, and w refer to pool, dry, and wet respectively

SLAM Validation with Bench-Scale Tests



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Summary and Conclusions

- Small and Intermediate-Scale Tests were done at SNL in 1980s
- Small scale tests were used to develop and validate SLAM model
- Immediate Scale Tests were used to observe the reactions of calcite and dolomite concretes with liquid sodium [45.36kg (100lbm)] for a reaction surface of 929.03 cm^2
- Brief description of the SLAM model provided
- Validation of the SLAM model using small scale tests provided

Future Implementation of SLAM in MELCOR

- SLAM has been implemented in CONTAIN-LMR
- Studies had been done for how to decouple from CORCON in CONTAIN-LMR
  - Based on accident progression in pool-type SFRs, corium-concrete interaction is not be possible for metallic fuel
- Methods to implement this SLAM without CORCON are being developed to be used in MELCOR
- Due to prioritization of MELCOR SFR development for MELCOR, SLAM implementation is not expected in the next couple of years