CONF-790816--5

SLSF Delayed Neutron Detection with the On-Line Sodium Sampling System

W. F. Heiberger, R. E. Holzworth, and P. R. Shire (EG&G Idaho Inc.)

Abstract

Final design has been completed for a 1 gpm sodium sampling loop which will withdraw a continuous stream containing failed fuel in solution from the primary circuit of the Sodium Loop Safety Facility. Breeder reactor fuels are tested to destruction in the primary loop when inserted into the Engineering Test Reactor at INEL. Provisions for draining contaminated sodium to the primary loop permits a disconnect of the sampling loop after each test. The sampling loop will contain a delayed neutron monitor located remotely from the test fuels being irradiated; transit time will be 12s at rated flow. Fission products carried in sodium solution will emit delayed neutrons primarily of groups 2 and 3 ($T_{1/2}$ = 22s and 6s) in the monitor and provide a delivered efficiency of 7% for all delayed groups.

SLSF Delayed Neutron Detection With the On-Line Sodium Sampling System

W. F. Heiberger, R. E. Holzworth, and P. R. Shire (EG&G Idaho Inc.)

An on-line sodium sampling system (OLSS) is being installed in the Sodium Loop Safety Facility (SLSF) at INEL. OLSS will provide real time detection of failed fuel pins via fission products deposited in the sodium. SLSF, now in its fifth test in the Engineering Test Reactor (ETR), permits failed fuel testing under simulated LMFBR transient conditions[1]. The OLSS loop will withdraw a sample stream from the SLSF primary loop, and transport it through a delayed neutron monitor (DNM). The oxide control and indication system is a subloop of OLSS used to purify the OLSS and SLSF sodium.

A diagram showing the OLSS system and its interface with the SLSF loop is shown in Figure 1; the normal sampling mode is shown. An electromagnetic (EM) pump provides a nominal OLSS sodium flowrate of .05 kg/s (1 gpm) with delayed neutron precursors in solution and transports them to the DNM in $\sim$12 seconds. The DNM consists of the sodium chamber, lead shielding, a moderator and an array of BF_3 detector tubes.

On startup, OLSS sodium is loaded from a hold tank. During the pre-test phase, the OLSS/SLSF sodium inventory is purified with a conventional cold trap and the purity verified with a plugging indicator. After the experiment the contaminated sodium is drained to the

SLSF loop and flushed with fresh sodium from the hold tank. As a safety feature, a shielded drain tank provides alternate disposal for OLSS contaminated sodium.

Following each SLSF test and draining of OLSS, the SLSF loop containing the test train is removed vertically into a shielded transport cask. This requires remote removal of the "pinch-off section" of the OLSS suction and discharge lines as shown on Figure 1. Disconnect is accomplished by a remotely operated severing tool. The reactor biological shielding is then removed allowing routine maintenance on the OLSS and the reactor.

Principal design parameters for the sampling system are shown in Table 1. Space constraints under the shielding required a compact design with components arranged in a ventilated enclosure. The requirement to operate the SLSF loop cover gas at a minimum pressure of 70 kPa (10 psia) to simulate current LMFBR design, imposes a constraint on sampling system pressure drop to the pump inlet to prevent cavitation. Sampling system pressure drop to the pump suction vs. flow rate is shown in Figure 2 along with required cover gas pressure. After reactor scram cover gas pressure will drop to 55 kPa (7.8 psia); for this condition the flow rate is decreased to .025 kg/s (0.5 gpm). A design margin >4 psi is available for cover gas pressure control over the design flow range.

TABLE 1. OLSS DESIGN PARAMETERS

	Metric	English
Sodium temperature	500°K - 900°K	400°F - 1200°F
Nominal flow rate at ΔP	.05 Kg/s at 100 kPa	1 gpm at 15 psid
EM pump flow rate and head	.30 kg/s at 250 kPa	6 gpm at 37 psid
Cover gas pressure range	70 - 300 kPa	10 - 45 psia
Tubing, 316 stainless steel	13 mm diam.	0.5 inch diam.

The sodium will transport delayed neutron precursors in solution; a significant fraction of these neutrons will be emitted while in the DNM. The transit time, t, of sodium from the failed fuel location to the DNM as well as the residence time in the DNM relate to efficiency of delayed neutron detection.

The rate at which delayed neutrons are born is the negative of the precursor decay rate:

$$\dot{N} = \lambda N_o e^{-\lambda t} \quad (1)$$

where:

t = time (sec)
λ = precursor decay constant (sec^{-1})
N_o = number of precursors at time zero
$\dot{N}$ = delayed neutron birth rate at time t.

The number of delayed neutrons released in the DNM during residence time Δt is given by integrating equation (1) between the limits of t and $t + \Delta t$:

$$N_\tau = \lambda N_o \int_t^{t + \Delta t} e^{-\lambda t} dt$$

$$N_\tau = N_o \, e^{-\lambda t} \left(1 - e^{-\lambda \Delta t}\right) \qquad (2)$$

The ith group of delayed neutrons represents β_i/β of all delayed neutrons emitted. Define f_i to be the fraction of the ith group which is released in the DNM.

$$f_i = \frac{N_{\tau, i}}{N_o} = \frac{\beta_i}{\beta} \cdot e^{-\lambda_i t} \left(1 - e^{-\lambda_i \Delta t}\right) \qquad (3)$$

The fraction of delayed neutrons released in the DNM by all groups is given by the sum:

$$f = \sum_i f_i = \frac{1}{\beta} \sum_i \beta_i \, e^{-\lambda_i t} \left(1 - e^{-\lambda_i \Delta t}\right) \qquad (4)$$

The values of λ_i and β_i represent average values for UO_2-PuO_2 fuel for 6 groups of delayed neutrons[2]. The transit time in the primary loop from the failed fuel to the sampling system suction line is 1.8 s at the primary loop nominal flow rate, 7.8 kg/s. To illustrate the effect of sampling system flow rate on the delayed neutron detection efficiency, equation (4) is plotted vs. sampling system transit time (t - 1.8 s) in Figure 2. The nominal sampling system flow rate .05 kg/s

(1 gpm) will deliver 7% of delayed neutrons to the DNM compared to the maximum of 8.5% observed at .15 kg/s (3 gpm). The major contributors are delayed groups two and three.

CONCLUSION

Predicted performance of OLSS for LMFBR fuels safety tests in SLSF assures adequate margin for constraints such as plenum pressure, pump cavitation, loop pressure drop and optimum transit time to the delayed neutron monitor.

References

1. G. L. Bordner, et.al., "Post Test Evaluation of the SLSF Loss-of-Flow Safety Experiment P2", Trans. Am. Nucl. Soc., 27,506 (1977).

2. G. R. Keepin, et.al., "Delayed Neutrons from Fissionable Isotopes of Uranium, Plutonium, and Thorium", Phys. Review 107(4), 1044, (1957).

Paper Title: SLSF Delayed Neutron Detection with the On-Line Sodium Sampling System

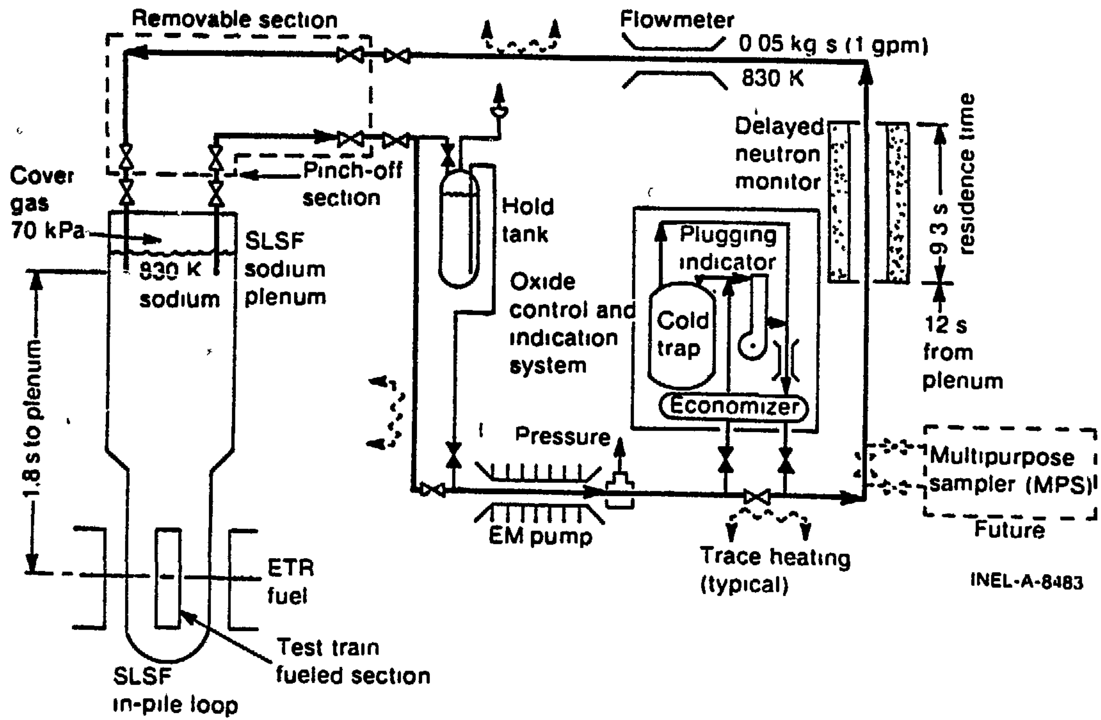
Authors: W. F. Heiberger, R. E. Holzworth, and P. R. Shire (EG&G Idaho, Inc.)

Figure Titles:

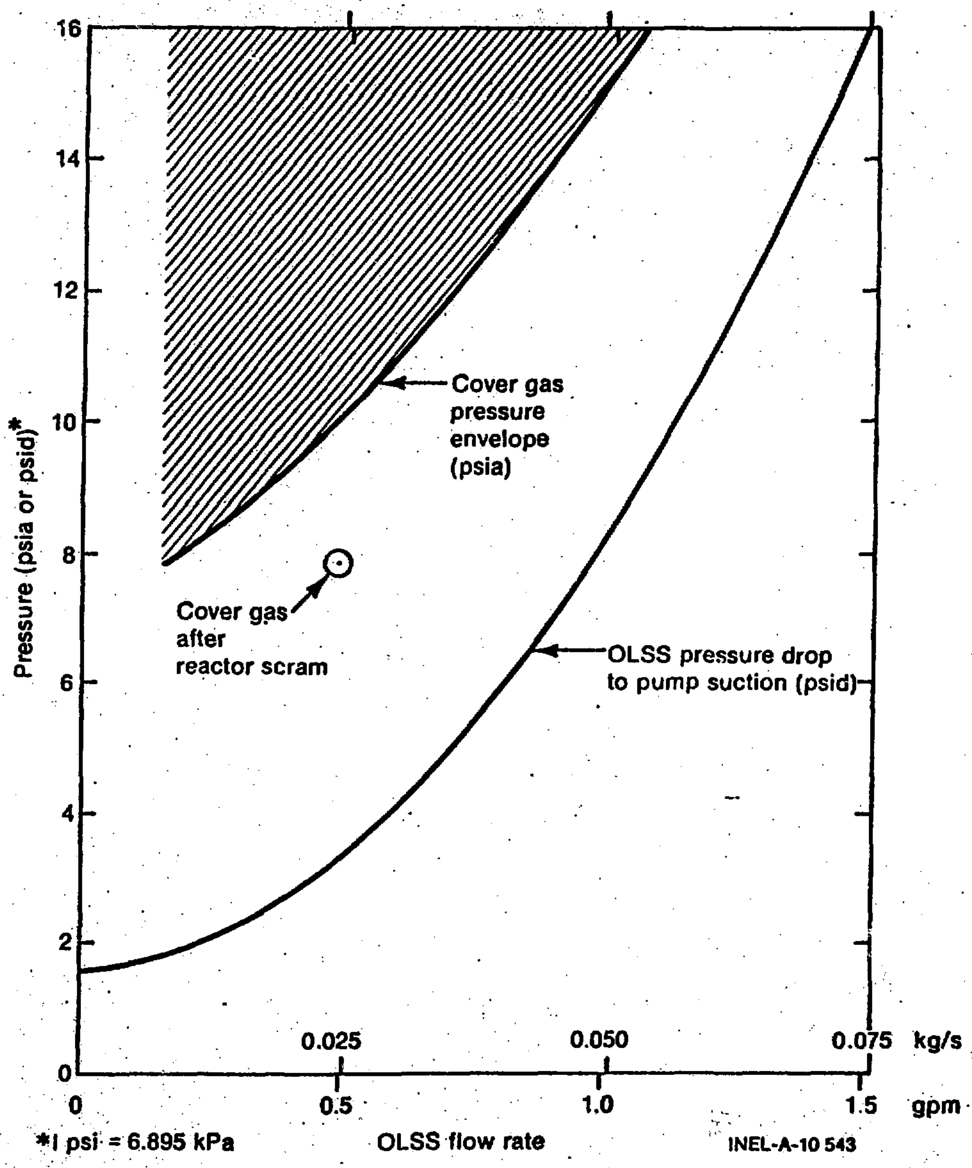
1. SLSF On-Line Sodium Sampling System and Interface with the In-Pile Loop in ETR.

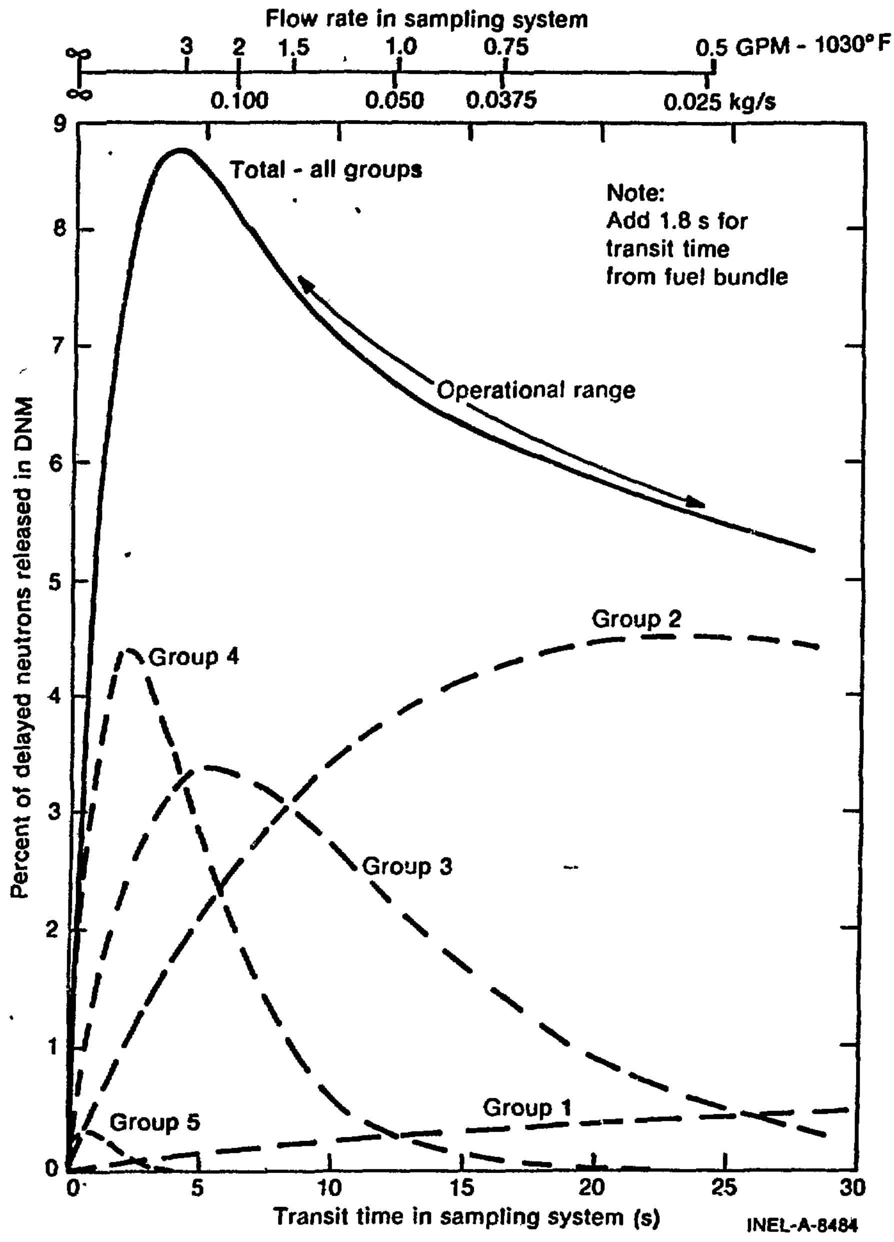
2. Sampling System Pressure Drop to Pump Suction and Cover Gas Design Pressure Requirements vs. Sampling System Flow Rate.

3. SLSF Neutrons Released in the Delayed Neutron Monitor VS. Transit Time in OLSS.



Removable section
Flowmeter
0 05 kg s (1 gpm)
830 K
Delayed neutron monitor
9 3 s residence time
12 s from plenum
Cover gas 70 kPa
Pinch-off section
Hold tank
SLSF sodium plenum
830 K sodium
Oxide control and indication system
Plugging indicator
Cold trap
Economizer
1.8 s to plenum
Pressure
EM pump
Trace heating (typical)
Multipurpose sampler (MPS)
Future
ETR fuel
Test train fueled section
SLSF in-pile loop
INEL-A-8483


Pressure (psia or psid)*
16
14
12
10
8
6
4
2
0
Cover gas
pressure
envelope
(psia)
Cover gas
after
reactor scram
OLSS pressure drop
to pump suction (psid)
0.025
0.050
0.075
kg/s
0
0.5
1.0
1.5
gpm
*I psi = 6.895 kPa
OLSS flow rate
INEL-A-10 543



Flow rate in sampling system
∞
3
2
1.5
1.0
0.75
0.5 GPM - 1030°F
∞
0.100
0.050
0.0375
0.025 kg/s
Total - all groups
Note:
Add 1.8 s for
transit time
from fuel bundle
Operational range
Group 2
Group 4
Group 3
Group 1
Group 5
Percent of delayed neutrons released in DNM
0
1
2
3
4
5
6
7
8
9
0
5
10
15
20
25
30
Transit time in sampling system (s)
INEL-A-8484