Fast Breeder Reactors Secondary Piping Potential Sodium Leakage Rate Assessment

Francesco Alicino, Sigfrido Cardini
ANSALDO SpA, Genova, Italy

INTRODUCTION

In the Liquid Metal Fast Breeder Reactors it must always be taken under control any possible air-sodium contact, because of the elevated air-sodium reactivity. This requires that LMFBRs be carefully designed so that over the entire plant life such an event can't occur in an uncontrolled way.

For these Reactors the operating conditions usually impose that a lot of life be spent in the creep regime and moreover generally severe hot and cold thermal transients are anticipated, which increases the potential of crack propagation. Then, a useful mean to ascertain if the above event can occur is to adopt a Fracture Mechanichs approach.

In such a way the potential for an initial postulated flaw becomes through-wall and unstable can be evaluated along with the determination of any possible leakage which leads to estimate the required Plant Leak Detection System sensitivity.

Two aspects are fundamental in a design phase:

a) To evaluate the maximum initial flaw size to be postulated at the beginning of life;

b) To estimate as accurater as possible the severest and most credible creep and fatigue sequence.

Since this last aspect involves the necessity to analyze a lot of postulated sequences of events, a computer program which allows to do that automatically sweeping all the anticipated operating conditions combinations, all over the plant life, is a very essential tool.

The ANSALDO CRAGROW computer Program has been developed to meet this requirement along with the possibility to treat various environments, materials and flaw configurations as well as to perform Fracture Mechanich calculations in compliance with different assessment procedures (ASME XI, R6, etc.).

In which is following a brief description of the main methodological features and the results, got by the application of such a study to the Italian PEC Reactor, are provided.

METHODOLOGICAL FEATURES

Initial Postulated Flaws Size and Location

A correct estimation of the maximum allowable flaw size which can be expected to be found in Safety Nuclear Pipings is the first and fundamental step to run. Safety Nuclear Components are subject to extensive and thorough examinations.

The acceptance criteria defined by the usually adopted Codes (ASME, RCC-MR, BS, and so on) are stringent enough to guarantee that the probability to operate flawed structures is very low.

In particular, all the Standards and Codes don't accept any like-a-crack (planar) indication.

Nevertheless, all the NDT techniques have a sensitivity threshold: indications whose size is below this value can be not detected. A critical evaluation of the acceptance criteria adopted by the Codes can permit to estimate the maximum allowable flaw size, that is the maximum flaw size which can't be detected with a high confidence level, which can vary depending on many factors (the required Safety Margin, the precision of the adopted NDT technique and so on - see, Reale et al., 1988 and Section XI task Group, 1986). Further statistical considerations have however to be developed on the type of materials and weldments, on fabrication procedures, inspections and dimensions in order to get reliable values for the postulated maximum allowable flaw size (Klein et al., 1987).

Making also reference to typical LMFBR pipe line materials (like type 316 Stainless Steels) and to pipe-line size ranging from 4" Sch. 10 S through 14" sch. 20, flaws 40 mm long and 0,2 mm deep have been found to represent the maximum initial flaws (see, Klein et al., 1987).

In a design approach also criteria on the localisation and orientation of the maximum postulated initial flaws have to be set. The ANSI/ANS-58.2 (1980) criteria can be usefully applied in such a case. Then the locations where the reference initial flaws have to be postulated coincide with those ones having the highest probability to fail because of the reduced safety margin against shakedown or the high cumulative usage factor.

The orientation of the reference flaw has to be choosen on the basis of the prevailing loadings on the pipe-lines. In the case that the bending moment is very important compared to pressure, and in particular for small size pipe (less than 4" nominal diameter), it can be shown that circumferential flaws are more critical than the longitudinal ones. Otherwise, longitudinal flaws have to be analyzed along with the circumferential ones. In any case the reference initial flaw is considered to lie on the inside surface of the pipe and to have semi-elliptical or other shape, depending on the length/depth ratio.

Creep and Fatigue Crack Growth Interaction

Two topics have to be faced from the point of view of creep and fatigue crack growth interaction. The first one is strictly related to the sequence of events which has to be postulated in a design phase in order to evaluate the worst but again credible creep and fatigue superposition on the standpoint of the reference initial flaw growth. The second topic is related to the Crack Growth laws to be used and in particular, to the values that the parameters of these laws shall have to well represent the behaviour of the material in the given environment. For LMFBRs the last one can be the most critical feature because of a certain lack of experimental data.

About fatigue the modified Paris law $da/dN = C \cdot [\mathrm{delta}K/(1-R/2)]^n$ (Sperandio, 1987) has been selected as representative of the behaviour of Stainless Steel materials in Sodium environment.

About Creep the results of an experimental work (Abe H. et al., 1987) have been used (with some engineering judgment to cover all the temperature range of interest).

The selection of the fatigue-creep combination to adopt has been automathized by implementation of a specific Ansaldo Computer Code (CRAGROW) whose fatigue routine is based on such an approach as that one required by the ASME Code to

evaluate the Cumulative Usage Factor (see, Fig. 1 for a synthetic flow-chart of the creep/fatigue routine).
At each extreme of the cycles which falls in the creep region a maintenance time is associated. This time is depending on the global expected duration for the specific event under consideration rated to the global occurrencies of the cycles which it is superimposed to.

Leak Flow Rate

To evaluate the Leak Flow Rate a through-wall crack is necessary. Then if the combined Fatigue/Creep crack growth analysis doesn't provide a through-wall crack as a consequence of the anticipated events, it needs that Fatigue/Creep events be repeated till such a crack is got. This procedure, too, has been automathized by implementation on the ANSALDO CRAGROW, being possible to the user to choice which events he likes to run again.
Once a through-wall crack is got, the leak flow rate is computed by means of the relation (Dezes, 1987)

$$q = (d^3\ l\ p)/60\ m\ t$$

where: d = width, l = length, p = pressure, m = dynamic viscosity,
t = thickness.

This relation accounts for sodium as flowing medium. The value so obtained has to be used to design the leak detection system.

Fracture Mechanics Analysis

The Fracture Mechanics Analysis is devoted to evaluate the margins against criticality for the detectable flaw size. Both Global (Net Section Collapse Criterion) and Local (J-T approach) stability are treated.
A Tearing-Stability analysis of the integrally plasticized flawed section is always run accounting for the compliance of the lines (Paris, 1977) in order to check if unstable crack growth can occur.
The approach used is extensively treated by Ranganath et al. (1983), Kumar et al. (1981), Tada et al. (1979) and Paris et al. (1983).

APPLICATION TO THE PEC PLANT

Application Description

The described methodology has been applied to the secondary pipe-lines of the Italian LMFBR PEC. Six pipe-lines have been considered: the hot and cold circuits of reactor, emergency and test channel cooling systems. Their dimensions are given in Tab. 1. The material is AISI steel: SA 376 TP 316 BF and SA 240 TP 316 BF for the bends. The mechanical properties are given in Tab. 2.

Results

The following results have been obtained:
1) End-of-life flaws are not through-wall (see Tab. 3); 2) Possible through-wall cracks (obtained cycling the most severe operating cycle) give leakage rates easily detectable, (Tab. 3) by the installed detection system (whose sensitivity is 1 cm^3/l'); 3) The instability mechanism is controlled by the Net Section Collapse Criterion for all the lines except for the Reactor Cooling System Hot Line; 4) No matter of unstable propagation of the Net Section Collapse Critical Flaws under integrally plasticized conditions, due to the compliance of the lines.

Conclusions

The examined lines can be operated safely on the point of view of sodium leakage since it has been proved that no through-wall cracks are expected during the life and any possible through-wall crack can be promptly detected before reaching criticality or unacceptable leakage rates (see, the analogous application for the CIRENE plant, Alicino et al., 1989).

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PIPE-LINE		NOMINAL DIAMETER ["]	SCHEDULE	WALL THICKNESS [MM]
REACTOR	H	14	20	12
	C	14	20	12
EMERGENCY	H	4	10S	4.5
	C	4	10S	6.02
TEST CHANNEL	H	4	10S	4.5
	C	4	10S	6.02

TAB. 1 PIPE DIMENSIONS WHERE THE FLAW IS POSTULATED.

YIELDING STRESS	SY	207 MPA
ULTIMATE STRESS	SU	517 MPA
FLOW STRESS	SF	362 MPA
FRACTURE TOUGHNESS (1)	JIC	700-1400 N/MM
J-R CURVE SLOPE (1)	DJ/DA	90 MPA
RAMBERG-OSGOOD PARAMETERS (1)	ALFA	1.69
	SIGMA0	207 MPA
	EPSILON0	0.001
	N	5.42

TAB. 2 MECHANICAL PROPERTIES OF STEEL AND RAMBERG-OSGOOD EQUATION PARAMETERS
(1) SEE RANGANATH S. ET AL.,1981.

PIPE-LINE		END-OF-LIFE DEPTH [MM]	CRACK OPENING AREA [MM**2]	LEAK FLOW RATE [CM**3/MIN]
REACTOR	H	0.26	1.55	300
	C	0.26	1.94	500
EMERGENCY	H	0.27	4.27	61600
	C	0.28	3.31	17000
TEST CHANNEL	H	1.46	2.00	7000
	C	0.48	2.88	13000

TAB. 3 END-OF-LIFE FLAW AND LEAK FLOW RATE OF THE CRACKS MADE THROUGH-WALL.

PIPE-LINE		HAS THE SECTION GLOBAL STABILITY ? MARGINS MOMENT		OPENING ANGLE	HAS THE FLAW LOCAL STABILITY ? J MARGIN	WHICH INSTABILITY IS REACHED FIRST ? T MARGIN (1)
REACTOR	H	73%	YES	623%	YES 155%	LOCAL -16%
EMERGENCY	H	6%	YES	24%	YES (T-MARGIN=224%)	GLOBAL 114%
	C	20%	YES	65%	YES 57%	GLOBAL 263%
TEST CHANNEL	H	34%	YES	98%	YES 169%	GLOBAL 115%
	C	34%	YES	98%	YES 202%	GLOBAL 260%

TAB.4 STABILITY RESULTS SYNTHESIS
(1) T-MARGIN=TR/TAPP-1

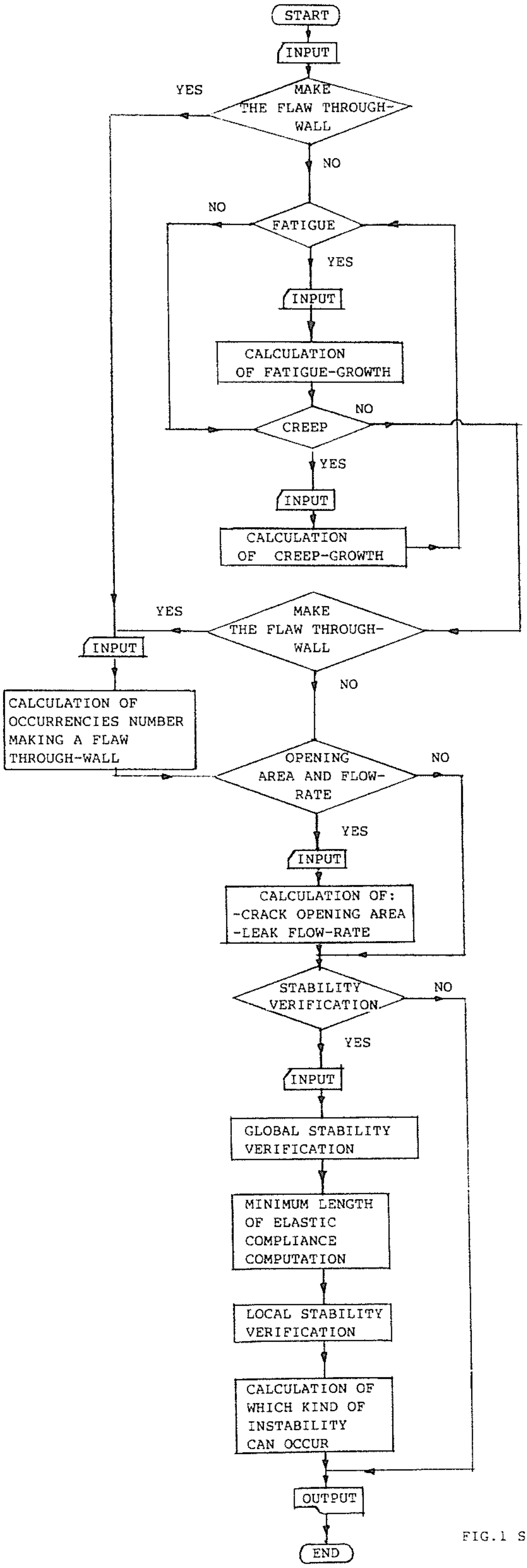

FIG.1 SEMPLIFIED CRAGROW FLOW-CHART