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ROD AND SCRAM BANK SIMULATION

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Introduction

In determining the behavior of the power and temperatures of a core during rod ejection and/or scram bank insertion, the characteristics of the rod or bank are clearly of importance. Not only is the actual velocity versus time behavior of the rod necessary, but the characteristics of the flux distribution that the rod "sees" are of equal importance in determining the fraction of the rod worth that has been inserted or withdrawn from the core. This latter point is automatically accounted for in an "r-z" or "x-y-z" calculation; but when the dynamics calculation is "x-y-t", or "r-t", then the motion/worth/time curve of the rod transverse to the "x-y" or "r" plane is not inherently prespecified.

The motion/time characteristics of a rod or bank can be easily prespecified, but the relation between the fractional rod withdrawal and the fractional reactivity insertion is, as we shall soon see, not at all a simple one.

When a rod is partially removed from a core, the flux distribution will skew away from the rodged end into the

higher reactivity unrodded end. Assuming a simple ϕ^2 weighting, it is clear that more than 50% of the rod worth will be introduced by the time the rod is 50% ejected. During the insertion of a scram bank the flux moves away from the region where the bank has been inserted into the unbanked region so that less than 50% of the bank worth is introduced by the time the bank is half inserted.

The bulk of this paper concerns the derivation and validation of a very simple method of predicting the reactivity change due to the motion of a rod or bank, and to the use of this method in dynamics calculations. In Fig. 1 we show the power/time response during the withdrawal of a 2.5% rod in 2.4 seconds for a typical BWR in an r-t calculation. The curve labeled C is produced by assuming that the cross section changes go as "t" (such a relationship might be obtained if the flux distribution in the axial direction were always flat). The curve labeled B is produced by an "S" shaped weighting (such a weighting might be produced if the axial flux were sine shaped during the transient). The curve labeled A is produced by a self-weighting technique which we shall discuss below. Fig. 2 shows the hot-spot centerline enthalpy

for these three weighting modes. It is clear that curve A (the self-weight approach) yields the most conservative result. The important question is what relationship exists between an r,z,t calculation and the r,t calculation.

Intrinsically, it seems possible to secure very close agreement between r,z,t and r,t calculations when the weighting technique is correctly chosen. Thus, Fig. 3 shows the r,t and r,z,t power/time response in a P.W.R. to the 0.1 second fading of a central region absorption with $\beta 1.21$. The perturbation is caused by a z independent cross section change (in the core, but not the reflectors). The differences in response can be traced almost completely to the different methods of achieving the initial equilibrium in NØAH and TWIGL (so that the absorption cross section changes are not worth exactly the same in the two cases). For this particular example, the correct weighting is known beforehand so that the r,t calculation correctly mocks up the r,z,t calculation.

The Self-Weighting Technique

The worth of a localized poison is often calculable from a knowledge of the flux and adjoint distribution in the absence of the poison. This will be an accurate approach if the presence of the poison does not seriously affect the flux/adjoint shapes. On this basis we can calculate, beforehand, the motion/worth curve of a very weak rod; this method yields the usual "S" shaped curve. If the initial flux was a sine then the motion/worth relation could be expressed as

$$\rho(t) = \rho_{\max} \left(\frac{Z(t)}{H} - \frac{\sin(2\pi Z(t)/H)}{2\pi} \right) \quad (1)$$

where $Z(t)$ is given by the actual velocity/time relation of the rod (e.g. $Z(t) = vt$; $t \leq H/v$).

In the presence of a partially inserted strong rod, the flux/adjoint shape changes markedly; thus it is not, a priori, reasonable to assume that eq. (1) should hold.

We consider now a one-dimensional, one-group, two-region model for a "window shade" rod; we reduce this to a particularly simple, dimensionless, form and show that a proper choice

of the parameters yields excellent agreement with 2-dimensional (r,z) 4-group, multiregion predictions of position/worth relation.

In the unrodded region of the core the flux is assumed to obey the equation

$$D \frac{d^2 \varphi_1}{dx^2} + \left(\frac{v\Sigma_f}{\lambda} - \Sigma_a \right) \varphi_1 = 0; \quad 0 \leq x \leq x_1 \quad (2a)$$

In the rodded region of the core the flux is assumed to obey the equation

$$D \frac{d^2 \varphi_2}{dx^2} + \left(\frac{v\Sigma_f}{\lambda} - \Sigma_a - \Sigma_R \right) \varphi_2 = 0; \quad x_1 \leq x \leq H \quad (2b)$$

The boundary and interface conditions are

$$\varphi_1(0) = \varphi_2(H) = 0 \quad (3a)$$

$$\varphi_1(x_1) = \varphi_2(x_1) \quad (3b)$$

$$D\varphi_1'(x_1) = D\varphi_2'(x_1). \quad (3c)$$

Further, when the rod is fully inserted we have $\lambda = 1$, and when the rod is fully withdrawn we find $\lambda = 1 + \Sigma_R / (\Sigma_a + D\pi^2/H^2)$. The method of solution (to find λ) is straightforward and will not occupy our attention, but it is not necessary to know the exact values of D , $v\Sigma_f$, Σ_a and Σ_R to reach this solution (and

indeed we feel that the accuracy of the "self-weight" method is due to this fact). Since $\lambda = 1$ for $x_1 = 0$, we find

$$\nu \Sigma_f = \Sigma_a + \Sigma_R + D\pi^2/H^2; \quad (4)$$

using this result eq. (2a,b) can be put into the form

$$\frac{d^2 \varphi_1}{dy^2} + B_1^2 \varphi_1 = 0 \quad ; \quad 0 \leq y \leq \alpha \quad (5a)$$

$$\frac{d^2 \varphi_2}{dy^2} + B_2^2 \varphi_2 = 0 \quad ; \quad \alpha \leq y \leq 1 \quad (5b)$$

where

$$B_1^2 = \frac{1 + (1 + \Sigma_R/\Sigma_a) (H/M\pi)^2}{\lambda} - (H/M\pi)^2 \quad (6a)$$

$$B_2^2 = B_1^2 - (\Sigma_R/\Sigma_a) (H/M\pi)^2 \quad (6b)$$

The input parameters are clearly Σ_R/Σ_a and $(H/M)^2$. The value of Σ_R/Σ_a is easily determinable if the real worth of the rod, λ_{Rod} , is known from multigroup calculations; thus,

$$\Sigma_R/\Sigma_a = (\lambda_{Rod} - 1) (1 + (M\pi/H)^2); \quad (7)$$

Since $(M/H)^2$ for the current class of light water moderated power reactors is $\approx 1/2500$, the value of Σ_R/Σ_a is very nearly

1.004 ($\lambda_{\text{Rod}} - 1$). Further, since we are interested in the relative worth (a function between zero and unity) we find

$$\frac{\Delta(1/\lambda)}{\Delta(1/\lambda)_{\text{max}}} = \frac{\pi^2 - B_2^2}{(H/M)^2 (\Sigma_R/\Sigma_a)} \quad (8)$$

hence, the only number of importance is the product

$$(\Sigma_R/\Sigma_a) (H/M)^2$$

In order to test the validity of the method we used a set of four group Oyster Creek cross sections and established an r,z model with a central, fully rodged region surrounded by (progressively) an unrodged region, and a partially (homogenized) rodged region. The central rod worth was found by eigenvalue calculations to be 0.0256. A series of eigenvalue calculations for the partially inserted rod has been completed, and are shown as the symbols (•) in Fig. 4. Using the standard value of $(H/M)^2 = 2500$ we calculated the one-dimensional, "self-weight", analogue and obtained the solid line in Fig. 4. Fig. 5 shows

¹In solving we choose B_1^2 , find B_2^2 from eq. (6b) and use the criticality condition to check the validity. A few choices of B_1^2 yields sufficient information to extrapolate to the correct value.

another calculation with different sets of cross section and region boundaries; again the symbols are 2-D results, while the solid line is the "self-weight" result.

The "self-weight" method and the 2-D comparison are static calculations. In Fig. 6 we show the effect of rod withdrawal in the axial direction from very low power. These calculations were done with NØAH, and account for delayed neutrons, temperatures, xenon and rod motion. The four cases shown have the rod fully withdrawn (or inserted) in 1. second. The upper two cases are ejections while the lower two are scram insertions. The output edit of NØAH calculates the uncompensated reactivity of the system and these results are plotted as solid lines. The symbols are, as before, self-weight predictions. The solid lines on the upper two cases stop because the power level has reached a sufficiently high value that feedback effects become a significant part of the uncompensated reactivity and the comparison ceases to have simple meaning. Clearly, however, the input reactivity (via the self-weight method) is essentially that which the core sees even during a prompt critical excursion. The scram cases (curves C,D) are more interesting

since the self-weight method seemingly fails (although conservatively) to yield a close mock-up to what the core sees in a transient. In a scram the prompt neutron distribution obeys the self-weight analysis but the delayed neutrons do not; hence, when the prompt neutrons have died out the scram bank worth is determined partly by a distribution (delayed flux) which more closely matches the before-scram flux.

The weighting is therefore done (in the transient case) with a higher weight flux. In a real situation, following some accident, it is probable that the flux will rise on a fast period and after a "trip" of one or another kind the reactor will be scrammed; here we can assume a much closer correlation (as in cases A,B) because during the excursion the flux will rise rapidly and leave the delayed neutron flux much further behind than at equilibrium.

At this point it is necessary to ask a question. While the results so far presented do seem to predict the worth vs. time function ($w(t)$) for the motion of a central rod,¹ and

¹We shall not consider x-y-t calculations since comparison presupposes the use of an x-y-z-t calculation as well. It seems reasonable to believe that a central rod of a given worth is not different from an off-center rod of the same worth.

this is of direct use in point kinetics, what relation does this function have with the time function $S(t)$ that must be applied to the cross sections in an r-t calculation? That is, the output edit of an r-t calculation for uncompensated reactivity must yield $W(t)$, but what input function $S(t)$ applied to the cross sections will produce this?

In Fig. (1-3) we spoke of certain types of weighting functions used in r-t calculations. These were functions $S(t)$ applied to the cross sections in the central rodded region. The assumption there was that the functions $S(t)$ and $W(t)$ were the same. We shall show that this is not usually true.

In Fig. (3) we showed a near perfect match between an r,z,t calculation and an r,t calculation. In this case the central region absorption cross section (in both calculations) varied as

$$\begin{aligned}\Sigma_a(t) &= \Sigma_a^0 + \delta\Sigma_a(T-t)/T, & t < T \\ &= \Sigma_a^0 & t > T\end{aligned}$$

In Fig. (7) we show the edit of the function $W(t)$ (the dashed line) in comparison to the function $s(t) = t/T$ as the solid

line. Clearly, $s(t) \neq W(t)$; but the function $s(t)$ is the correct one to apply in the r,t calculation to assure a correct comparison with the r,z,t calculation.

In Fig. (8) we consider another r,t calculation. Here we mock up the withdrawal (in 2.4 seconds) of a bank worth 2.2%, and which is assumed to be homogeneous radially, by assuming $S(t)=W(t)$. Although the initial power is only 2.75 kw, extensive feedback effects show up by 0.9 seconds and by 1.2 seconds the peak/average is down 15%. These effects tend to decrease Σ_a ; hence, increase M . The symbols in Fig. (8) which appear in the high feedback range are obtained by adding to the uncompensated reactivity, the Doppler reactivity; it is not clear how much error is involved in this approach. Nonetheless, by neglecting the xenon and moderator feedback the symbols fall too low. While neglecting the increase in M in calculating $W(t)$ by the self-weight method puts the predicted $W(t)$ too high and we conclude that in mocking up a full radial coverage scram bank (either for withdrawal or insertion) the correct function $S(t)$ to use is $W(t)$ as calculated by the self-weight method. This is

still more clearly seen in Fig. (10) for the insertion of a 1% scram bank in the absence of delayed neutrons. Here the calculated $W(t)$ follows the predicted $W(t)$ extremely closely even though we use $S(t) = W(t)$. In this case no significant change in P/A power occurs during the shutdown.

When we approach the question of the isolated (central or other) control rod in an r, t (and presumably x, y, t) calculation we meet the first clear failure. Fig. (11) is a more detailed study of the case first presented in Fig. (5). The use of $S(t) = W(t)$ leads in an r, t calculation to the symbols below the solid line. That is, $S(t) = W(t)$ clearly underpredicts the amount of reactivity that should be added to the system.

If we return to our earlier analysis Eq. (2-6) we can reduce the system to the following relation

$$\int_0^H dx \left[D\varphi'' + \left(\frac{\nu\Sigma_f}{\lambda} - \Sigma_a - \Sigma_R(1-F(x)) \right) \varphi \right] \varphi = 0 \quad (9)$$

where

$$F(x_1) \equiv \frac{\int_0^{x_1} \varphi^2(x) dx}{\int_0^H \varphi^2(x) dx} \quad (10)$$

$F(x_1)$ would seem to be a close relation to the function $S(t)$ and if we make use of this correspondence, we determine the upper symbols in Fig. (10), a clearly conservative estimate. Using $S(t) = F(x_1(t))$ introduces reactivity too rapidly.

Both functions $S(t)$ lead to an underprediction of $W(t)$ in the power range. It is not clear whether this is due to a failure to account for the reactivity in xenon and moderator feedback and the feedback effect on M^2 , or to the flattening of the flux due to all forms of negative feedback. In the latter case the worth of the ejected rod would be asymptotically less than predicted by the free period calculation in a step ejection. Fig. 11 shows the response due to ejecting a 3.52% rod; the phenomena are similar to the 2.5% case. In Fig. 12 we show the effect for a 1.31% rod. Here, neither function $S(t)$ leads to a calculated $W(t)$ which is an upper bound to the predicted $W(t)$.

It is clear that even though we have a scheme which, presumably, predicts the worth/time function for the ejection

of a central rod, we do not as yet have a clear means of predicting the function $S(t)$ which will produce the correct transient. It is possible, however, to outline an iterative scheme which would do just that.

An Iterative Scheme for Finding $S(t)$

We assume that we have available the spatial distribution of cross sections before the rod is ejected (these are labeled $\Sigma(0)$). The predicted value of $W_p(t)$ is known and an initial value of $S^0(t) = W_p(t)$ is chosen. Using this value of $S(t)$ the cross sections, $\Sigma(t)$, are corrected for rod motion and a set of fluxes $\phi^i(t)$ is calculated from the earlier set $\phi^\infty(t-\Delta t)$. These fluxes are used with the cross section set $\Sigma(0)$ to calculate $W_c^i(t)$ and this is checked against $W_p(t)$; a new value $S'(t)$ is chosen (depending on $W_c^i \leq W_p$), the set $\Sigma(t)$ is corrected for rod motion and a new set of fluxes $\phi^{i+1}(t+\Delta t)$ is calculated. These fluxes are used to determine $W_c^{i+1}(t)$ and extrapolating on $S^i(t)$ ultimately $W_c^\infty(t) = W_p(t)$ and the next time step begins.

Another Method of Calculating $S(t)$

Using the function $W_p(t)$ as a guide, a series of static radial or x-y calculations are performed using various numbers S_i as the weights for the rod cross sections. These calculations yield a set of numbers W_i which when compared with

$W_p(t)$ yield the desired correspondence $S(t) \longleftrightarrow W_p(t)$. This can be entered into a code as a table or a fitted function.

Figure 13 shows a comparison of several forms for $S(t)$ with the correct one calculated as just described for the 2.5% rod case.

A Simple Analytical Approximation

Clearly, a fitted function of $W(t)$ and $S(t)$ vs. t is more desirable than a table or iterative scheme. We show now that it is possible to fit a very wide range of rod worths with a single parameter fit.

We observe that all of the curves of $W(t)$ and $S(t)$ are skewed "S-shaped". This means that they can all be mapped onto the same curve by a transformation of the spatial variable. The base curve we choose is that of Eq. (1).

$$Y(t) = y(t) - \frac{\sin(2\pi y(t))}{2\pi}, \quad 0 \leq y \leq 1 \quad (11)$$

Here, Y is either W or S . The relationship between $y(t)$ and $Z(t)/H$ will be different for W and S . If we let $z(t) = Z(t)/H$ be the unrodded distance, then an examination of the relation between $y(t)$ and $z(t)$ is made as follows: Given a rod worth and H/M value the self-weight method yields $W(t)$ vs. $z(t)$;

from the standard curve (Eq. (11)) we find $y(t)$ from $Y(t) = W(t)$. Similarly, for $S(t)$ from the numbers S_i . It is observed that for all rod withdrawals $y(t) > z(t)$ and for all insertions $y(t) < z(t)$. Because of the symmetry between insertion and withdrawal we need only consider one (withdrawal).*

In Fig. 14 we show several of the curves of y vs. z for $W(t)$. It is seen that in the 45° rotated reference frame $y'-z'(t)$, all the curves are symmetric about $z' = \sqrt{2}/2$. In fact, the curves have the approximate representation

$$y' = a(z')^2 (\sqrt{2}-z')^2,$$

transforming back we find

$$y = z + a_0 (y+z)^2 (1-(y+z)/2)^2 \quad (12)$$

This is the one parameter implicit fit for y vs. x . The method of finding y from z is iterative and generally converges in 3-6 trials. Because of the seeming universality of the self-weight method we can determine a_0 for a full range of the product $\Delta^{1/\lambda} \max (H/M\pi)^2$ for $W(t)$. It is impossible to secure a universal fit for $S(t)$. This is due to the fact that $S(t)$ is a fictional fractional change in the

* If H is the core length and x the inserted distance,

$$W_{\text{INSER.}}(x) = 1 - W_{\text{WITH.}}(H-x).$$

cross section, this is calculated in a radial or x,y geometry and depends on the actual area covered by the rod as well as the radial location, i.e., on the local radial flux distributions. The same is not true for $W(t)$ which depends more on the axial distribution. It is necessary to calculate $S(t)$ for each different case. In all cases studied a decrease of 75% in cross section (corresponding to $y(t) = 0.6324$) is nearly at the maximum of y - z and yields the best fit for a_o . This is shown in Table 1.

Table 1

A Single Parameter Fit to $W(t)$

$\Delta^1/\lambda_{\max} (H/M\pi)^2$	a_o for $W(t)$	$\Delta^1/\lambda_{\max} (H/M\pi)^2$	a_o for $W(t)$
0.0	0.0	10.120	.8484
0.253	.0302	12.650	.9322
1.265	.1532	18.975	1.2032
2.530	.3056	25.300	1.3330
5.060	.5524	37.950	1.5600
7.590	.7170	50.600	1.6701

Some Interesting Conclusions

The results so far presented imply that the self-weight method accurately predicts the relative worth of a strong rod by static calculations and that it also accurately predicts the transient worth in axial calculations. It does not (as accurately) predict the transient worth in insertion (during scram), because of the residual delayed neutron flux; but here the result, while less accurate, is nonetheless conservative.

Calculations show that the self-weight method does not directly yield information on the function $S(t)$ which is needed in r, t or x, y, t calculations to simulate the ejection of a rod in the z direction. Using $S(t) = W(t)$ seems to be always an underestimate of the correct function while $S(t) = F(x_1(t))$ is sometimes an upper bound, but not always. It is possible to describe an iterative scheme for calculating $S(t)$ but this has not been implemented. It is also possible to describe a means of calculating an input function for the correct $S(t)$; this has been implemented in one case.

Of more interest is the result that for a strong rod neither the pure ramp (flat weight) nor the "S" curve Eq. 1 is either accurate or conservative. Figs. 4-6 show clearly that much more of the rod worth is introduced by the $1/2$ insertion time than $1/2$ the worth. Indeed, we see that $3/4$ of the worth is inserted by $1/2$ time for a 2.5% rod. This is due to the fact that in large cores the flux skews strongly towards the unrodded end of the core. This leaves (relatively) little flux in the rodded end; hence, the worth of the rodded end is much less than normally thought. Similarly, when a scram bank is inserted for the first few feet, the flux skews away from the rodded end leaving only the change in buckling as a reactivity decrease. This is seen most clearly in the lower curves of Figs. 5, 6 where at the $1/2$ insertion point we have the following results:

Table 2

Fraction of Scram Bank Worth Seen by the Core
at 1/2 Insertion

Rod Worth	Worth/Max Worth	Inserted Worth
2.44%	0.25	.00610
4.12%	0.2	.00814
6.64%	0.14	.009296

For very powerful scram banks, one can expect a maximum effect at 1/2 insertion of a decrease of core length by a factor of 2; this would be about 1.6% (in a 12 foot long core, less in a larger one).

This conclusion is arrived at in the following way. The axial leakage is $< M^2 \pi^2 / H^2$ which for a 12 foot water moderated core (with $M^2 \approx 50 \text{CM}^2$) is about 0.004. If a scram bank of very large worth is inserted, its maximum effect at half insertion is to reduce the flux to zero along its inserted length and to reduce the core length by a factor of 2 and increase the leakage by a factor of 4. Thus, the decrease in k is < 0.016 . Actual calculations

(4 group, 2D; using 2DB) show that these conclusions are indeed accurate. Thus, in Table 2 we show the calculated value of k_{eff} for two reactors of B.W.R. type. The first column lists k_{eff} if we shorten the reactor (effectively setting the fluxes to zero at an earlier space point); the second column lists k_{eff} if we insert the cross section set related to the scram bank up to the same space point.

Table 3

A Comparison of the Effect of a BWR Scram Bank on k_{eff} with a Simple Shortening of the Core

Centimeters inserted	<u>Shortened Core</u>		<u>Scram Bank</u>	
	Case A	Case B	Case A	Case B
0	1.01771	1.00802	1.01771	1.00802
18.25	1.01769	1.00801	--	--
36.50	1.01765	1.00799	1.01768	1.00801
73.00	1.01733	1.00798	1.01753	1.00797
100.38	1.01655	--	--	--
127.75	1.01486	1.00640	1.01629	1.00767
182.5	--	1.00500	--	--
228.13	--	0.99231	--	1.000342

The two cases differ in that in case A a central control rod is inserted to a depth of 127.75 cm while in case B it is inserted to a depth of 237.25 cm. Case B initially shows greater skewing than case A so that the scram bank (which is worth 9.818% since part of the bank is already inserted) initially enters the core in a weaker flux zone than in case A; hence, is worth less. The calculations are converged to 5×10^{-6} so that the expected error is 1 part in the fifth decimal place.

These results imply that the scram bank is considerably slower in inserting negative reactivity than we had thought. The two cases above show that at 1/2 insertion only about 0.3% in negative reactivity has been inserted. Examination of Fig. 2, line A, shows that most of the fuel enthalpy rise occurs in the post-prompt burst period. Since BWR scram banks take 3 to 5 seconds for full insertion one can expect from the results of Table 3 that no significant change in the power/time shape (hence, enthalpy rise) will occur until somewhat after about 2 seconds.

Figure 1

MODEL OF 2.5% B.W.R. ROD DROP IN 2.4 SECONDS

Figure 2

FUEL ENTHALPY FOR A 2.5% ROD DROP IN A B.W.R.
HOT-SPOT CENTER-LINE ENTHALPY

Figure 3

A COMPARISON OF A 1-D and 2-D VERSION OF
A CENTRAL ROD EJECTION

Figure 4

A COMPARISON OF THE WORTH FRACTION OF A
2-D CENTRAL ROD WITH A 1-D PREDICTION

FRACTION OF ROD WORTH SEEN BY THE REACTOR

Figure 5

COMPARISON OF 2-D CENTRAL ROD WORTH WITH 1-D PREDICTION

Figure 6

SIMULATION OF MOVING CONTROL RODS AND
SHUTDOWN BANKS IN LARGE REACTORS

Figure 7

A COMPARISON OF THE INPUT FUNCTION $S(t)$
WITH THE OUTPUT EDIT OF $W(t)$

Figure 8

A COMPARISON OF THE PREDICTED AND CALCULATED
VALUE OF THE REACTIVITY FUNCTION $W(t)$ FOR THE
REMOVAL OF A RADIALLY UNIFORM BANK WORTH 2.2%
USING $S(t) = W(t)$

Figure 9

A COMPARISON OF THE PREDICTED AND CALCULATED
FUNCTION $W(t)$ FOR THE INSERTION OF A RADIALLY
-UNIFORM BANK WORTH 1% USING $S(t) = W(t)$
DELAYED NEUTRONS ARE NEGLECTED IN THIS
CALCULATION

Figure 10

A COMPARISON OF THE PREDICTED AND CALCULATED
FUNCTION $W(t)$ FOR THE EJECTION OF A 2.5% ROD

Figure II

A COMPARISON OF THE PREDICTED AND CALCULATED
FUNCTION $W(t)$ FOR THE EJECTION OF A 3.5% ROD

Figure 12

A COMPARISON OF THE CALCULATED AND PREDICTED
FUNCTION $W(t)$ FOR THE EJECTION OF A 1.3% ROD

Figure 13

A COMPARISON OF SEVERAL OF THE FUNCTIONS $S(t)$
WITH THE CORRECT ONE FOR A 2.5% ROD EJECTION

Figure 14

THE RELATIONSHIP BETWEEN THE
STRETCHED COORDINATE " $y(t)$ " AND
THE PHYSICAL COORDINATE " $z(t)$ "