

AN ABSTRACT OF THE THESIS OF

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Title: Oxidation of Zircaloy-4 in Pressurized Water
Reactor Conditions

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A study of the oxidation of zircaloy in reactor environments has been undertaken with the goal of characterizing of the Thermal Gradient Test Facility (TGTF) at Teledyne Wah Chang, Albany. A set of oxidation models is presented from the literature, as well as an extensive database of published oxidation test results. The question of the acceleration of zircaloy oxidation by aqueous lithium hydroxide is examined, with static autoclave test results compared to published models and results. Theories of the possible concentration of lithium hydroxide in operating reactor systems are presented. Large increases in the oxidation rate are investigated, with the possible use of lithium hydroxide accelerated oxidation in a short-term, in situ examination of the corrosion of a simulated fuel rod under heated conditions. Finally, a

manual for the use of the database is presented, for the continuing existence of the database at OSU for future researchers.

Oxidation of Zircaloy-4 in Pressurized
Water Reactor Conditions

by

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OXIDATION OF ZIRCALOY-4 IN PRESSURIZED WATER REACTOR CONDITIONS

1.0 INTRODUCTION

With the current push for longer burnups from fuel rods to increase plant capacity, longer in-reactor exposures for rods is becoming desirable. The limiting factor to rod life may become the oxidation of the cladding on the rod. This project examines the oxidation of zircaloy in reactor environments.

The problem involved in the examination of zircaloy oxidation is the difficulty in performing reactor-like tests of cladding. The Thermal Gradient Test Facility (TGTF) at Teledyne Wah Chang, Albany was designed to simulate a single, heated rod under flow conditions. The goal of this thesis is twofold: investigate the models for the oxidation that may be expected in normal TGTF operation; and determination of means to accelerate that oxidation in order to perform short-term, in situ measurements of oxidation occurring on a heated rod under flow conditions.

To characterize the oxidation that will occur in the TGTF, investigation into several established oxidation models was accomplished, and a large database of published oxidation data was constructed. The database will remain in archive at OSU, with additional

data sets added to it as they become available. This large store of data may prove invaluable to other researchers in the future. A manual for the use of the database is included as an appendix to this thesis.

Construction of the TGTF has been completed. Unfortunately, it does not appear to be suited for long-term (days to weeks) operation. Initially, it appeared that short-term oxidation testing would also be impossible, due to the long time periods necessary to build up significant oxides on the zircaloy surface. But the search for ways to increase the oxidation rate under relatively normal conditions (that is, using materials which might be found in PWR coolant) led to the investigation of lithium hydroxide accelerated corrosion, and the static autoclave tests presented herein. Additional investigation has shown that appreciable LiOH concentration is possible in normal operating conditions, especially if there is a pre-existing oxide and crud layer, as would be present in a long exposure, high burnup fuel rod. The increasing oxidation effect could feed upon itself, with higher oxide thicknesses causing insulation and thus higher temperatures, increasing the concentration effect, increasing the oxidation rate. Clad failure due to excessive oxide thickness could result from this effect.

2.0 LIGHT WATER OXIDATION OF ZIRCALOY

When zircaloy oxidizes in water, it forms an adherent, protective oxide layer. The speed at which this oxidation occurs follows two rate laws. The first, called the pre-transition growth regime, leads to a rate law where the oxide thickness (or weight gain per unit area) grows at a rate which is proportional to the cube root of the exposure time. This means that the initial oxidation is rather rapid, and then the growth rate levels off quickly. Once the oxide reaches a critical (also known as transition) thickness, however, the oxide growth rate becomes linear with time, theoretically unto infinity, although very thick oxide layers (hundreds to thousands of times the transition thickness) tend to spall, or flake off due to mechanical stress. A typical oxide growth curve for zircaloy is displayed in Figure 1.

In order to predict the oxide thickness for fuel rods in nuclear power plants, several models have been developed. Most of these models have been created using data from ex-reactor (autoclave) testing, and are then extrapolated to reactor conditions. Research into these models was done with the goal of modifying them slightly for the special circumstances and conditions involved in the TGTF project. Several of the most commonly used are

discussed below.

Typical Zircaloy Oxidation vs Time

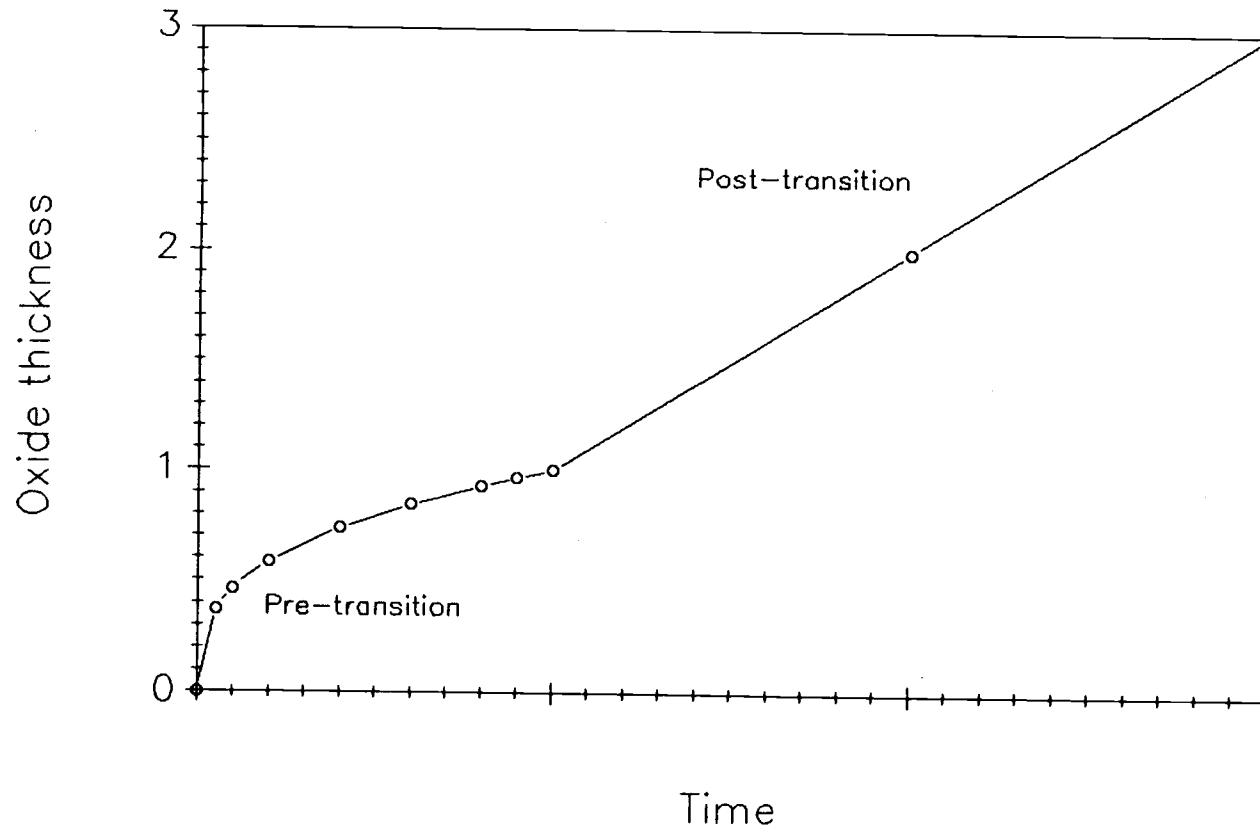


Figure 1

2.1 Literature Review of Available Models

2.1.1 Hillner

The Hillner model is important in that it is the standard model upon which many others are based. Hillner [1] generated corrosion versus time curves using data presented in twelve separate published reports on corrosion of zircaloy 2 and 4, including both pre- and post-transition behavior. All the zircaloy corrosion data gathered were compiled into a single isothermal corrosion curve, assuming that pre-transition kinetics were cubic and post-transition linear. Values of k_c and k_l , the cubic and linear rate constants, were determined from the compiled data, and yielded the following expressions:

$$\text{pre-transition : } W^3 = 6.36 \times 10^{11} \exp(-13636/T) \times t$$

$$\text{post-transition: } W = 1.12 \times 10^8 \exp(-12529/T) \times t$$

Where:

W is the weight gain (mg/dm²)

T is the absolute temperature (K)

t is the total exposure time (days)

These expressions, valid in a temperature range from about 260-400°C, yield the following expressions for the weight gain at transition and time to transition for each temperature:

$$W_t = 7.53 \times 10^1 \exp(-553.6/T)$$

$$t_t = 6.73 \times 10^{-7} \exp(11975/T)$$

Where:

W_t is the weight gain at transition (mg/dm²)

t_t is the time to transition from cubic to linear kinetics (days.)

T is the absolute temperature (K)

2.1.2 CHORT

Clayton and Fischer [2], conducted water corrosion tests at 633°K to determine the corrosion and hydriding characteristics of zircaloy-4 tubing. The CHORT model was developed to account for differences between SRA (stress-relief annealed) and RXA (recrystallized annealed) zircaloy-4 tubing. This model concerns the post-transition region of corrosion, and is based on the

work of Bryner [3].

The CHORT computer program calculates the thermal corrosion weight gain from the equation:

$$W_{TH} = (A \exp(-Q/T) \times t)^{1/3}$$

Where:

W_{TH} is the thermal corrosion weight gain per unit area. (mg/dm²)

A is the fitting constant for thermal corrosion

Q is the activation constant for thermal corrosion

T is the cladding surface temperature (K)

t is the time (days)

CHORT accounts for the accelerated corrosion by fast-neutron exposure (> 1 MeV) by a simple proportionality:

$$W_{RAD} = R \phi_f t$$

Where:

W_{RAD} is the radiation induced corrosion weight gain (mg/dm^2)

R is the proportionality constant for irradiation-induced corrosion

ϕ_f is the fast (Energy > 1 MeV) neutron flux ($\text{n}/\text{cm}^2\text{-s}$)

t is the time (days)

Total weight gain is calculated simply by adding the thermal and radiation induced weight gain as follows:

$$W_{TOT} = W_{TH} + W_{RAD}$$

Each time the total weight gain, W_{TOT} reaches the experimentally fit weight gain to transition, W_{TR} , the cubic corrosion kinetics are repeated for another iteration. In other words, CHORT calculates the post-transition kinetics (which were linear in the Hillner

model) by repeated iteration of the cubic pre-transition behavior. This assumption is based on observations of cyclic oxide growth in some data sets.

To compare CHORT calculations to commercial power reactor experience, temperature-dependant irradiation-induced corrosion enhancement factors, F_T , were incorporated into CHORT as follows:

$$F_T = 2.343 \times 10^3 \exp(-0.011557T)$$

Where:

F_T is the corrosion enhancement factor

T is the cladding surface temperature in $^{\circ}\text{K}$

An overall comparison of CHORT-generated data sometimes over-predicts and sometimes under-predicts the true values. The reasons behind this may stem from some of the assumptions made by CHORT, such as constant time to transition, and cyclic-cubic post-transition behavior.

2.1.3 Stehle

In the appendix to their report, Stehle, Kaden and Manzel [4] derive the equations used in their research comparing external corrosion of various PWR cladding materials. This model is important as it describes the oxidation characteristics under heat flux conditions, such as those in the TGTF.

The results of their analysis are given as:

$$w = w_0 + (RT_0^2 l / g Q q'') \ln \{ 1 - (g Q q'' / RT_0^2 l) k_0 \exp(-Q/RT_0) t \}^{-1}$$

Where:

- w is the weight gain (mg/dm²)
- w₀ is the weight gain at transition (mg/dm²)
- k₀ is the rate constant (in g/cm² day)
- Q is the activation energy (kcal/mol)
- R is the gas constant (kcal/mol K)
- T is the absolute temperature (K)
- q'' is the heat flux (W/cm²)
- l is the thermal conductivity (W/cm K)
- T₀ is the temperature at the surface (K)
- g is the specific volume (cm³/g)
- t is the time (days)

A characteristic time can be regarded as:

$$\tau = [RT_0^2 \exp(Q/RT_0)]/(Qq''k_0)$$

Formally, this means that the first equation yields a weight gain that increases indefinitely.

2.1.4 Pyecha

Pyecha, et. al. [5] obtained oxidation measurements from the waterside surface of 132 reactor-irradiated rods with fuel of various burnups using non-destructive eddy-current testing. The average oxide thickness of the rods was compared against predictions from the in-reactor oxidation model (see below) developed in the EPRI/C-E/KWU waterside corrosion code.

The following equations were used in that code:

$$\text{pre-transition : } dS/dT = (A/S^2)\exp(-Q_1/RT)$$

$$\text{post-transition : } dS/dT = C \exp(-Q_2/RT)$$

$$C = C_0 + U(MO)^P$$

oxide thickness at transition:

$$S_t = D \exp(-Q_3/RT - ET)$$

Where:

dS/dT = oxidation rate, $\mu\text{m}/\text{d}$

S = oxide layer thickness, μm

T = metal-oxide interface temperature, K

O = fast neutron flux, n/cm^2

R = universal gas constant, $\text{cal}/\text{mol K}$

$A = 6.3 \times 10^9$, $\mu\text{m}^3/\text{d}$

$C_0 = 8.05 \times 10^7$, $\mu\text{m}/\text{d}$

$D = 2.14 \times 10^7$, μm

$E = 1.17 \times 10^{-2}$, $1/\text{K}$

$M = 7.46 \times 10^{-15}$, $\text{cm}^2\text{s}/\text{n}$

$p = .24$

$Q_1 = 32,289$ cal/mol

$Q_2 = 27,354$ cal/mol

$Q_3 = 10,763$ cal/mol

$U = 2.59 \times 10^8$ $\mu\text{m}/\text{d}$

The numerical valued constants are not explained in the text of Pychea's report. Some appear to be physical constants (Q_1 , Q_2 , Q_3 are obviously activation energies), while others appear to be fitting constants (p , for example).

The predicted and measured oxide thicknesses are in very good agreement for groups of cladding rods having similar power histories. The model is, however, very temperature-sensitive, and has a tendency to overpredict oxide thickness.

2.1.5 Garzarolli

Garzarolli, et al. [6] use a very similar model to that described by Hillner, above. That is, a cubic pre-transition and linear post-transition area, proportional to $\exp(Q/RT)$ where Q is the activation energy, R is the gas constant, and T is the absolute temperature.

2.1.6 Dollins and Jurisch

Dollins and Jurisch [7], created a model for oxidation of Zirconium-based alloys based on the theory that electron or oxygen transport is rate-controlling, and not reactions at either interface. The Dollins and Jurisch model is important in that it is not simply a curve fit to existing data, but a complete derivation of oxidation kinetics.

They start with the transport equation for oxygen diffusion along grain boundaries:

$$dC_0/dt = d/dX(D_0 dC_0/dX) + dC_V/dX$$

Where:

C_0 is the oxygen concentration

C_V is the oxygen vacancy concentration

t is the time

X is the distance from the oxide to the oxide-water interface

D_0 is the effective coefficient for diffusion of water along grain boundaries. it is given by:

$$D_0 = 1.05 \times 10^{-3} \exp(-29300/RT)$$

or, in the presence of hydrostatic stress:

$$D_0 = 1.05 \times 10^{-3} \exp(-29300/RT) \exp(-V_0 h/kT)$$

Where R is the gas constant and the last term of the bottom equation is the loss rate of oxygen combining with vacancies.

Two additional equations are necessary for solution:

$$C_v(t) = [6C_{vi}/\pi^2] \sum_{n=1}^{\infty} \frac{1}{n^2} \exp -[D_v n^2 \pi^2 t' / \beta^2]$$

and

$$dX'/dt = -D_0^*(dC_0/dX)_{ox} + .76D_0^*(dC_0/dX)_{met}$$

Where:

C_{vi} is the initial vacancy concentration

t' is the time since the grain in question was formed

D_v is the vacancy diffusion coefficient given by:

$$D_v = 1.1 \times 10^{-3} \exp(-31000/RT)$$

X' is the oxide thickness

The second equation is the growth rate of the oxide, with the two parts of the LHS being the flux of oxygen into or out of the metal-oxide interface.

By the use of the above equations, a computer program was developed to predict the growth rate of oxide prior to transition. This was done for temperatures ranging from 260-700 °K. The data produced from the program provides an agreement to experimental that the authors state is "reasonable".

Figure 2 compares the Hillner, Pychea, and CHORT models

Model Comparison

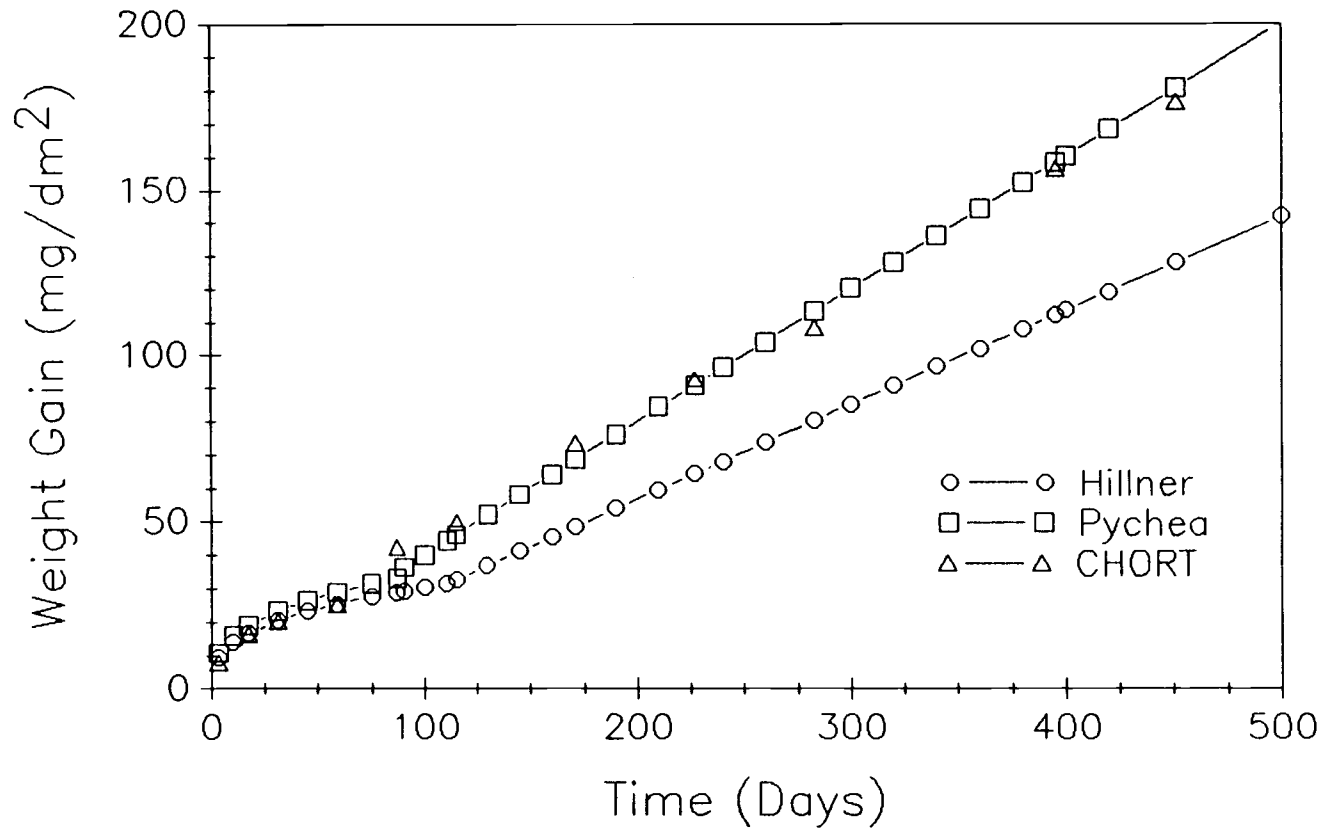


Figure 2

3.0 LITHIUM HYDROXIDE ACCELERATED OXIDATION

The oxidation of zircaloy in pure water is a relatively slow process, with experimental times on the order of days to weeks. The goal of the TGTF project, however, is to observe real-time, in situ oxidation of zircaloy-4 under heated conditions. Much research has been done for this project to determine a means to increase the oxidation rate, and the best found has been the addition of high concentrations of lithium hydroxide to the water. This section explores the use of lithium hydroxide to increase the oxidation rate of zircaloy-4 in water to allow real-time use of the TGTF to evaluate the effects of heat flux on the oxidation kinetics of zircaloy in PWR reactor chemistry environments.

3.1 Theory

Very little data has been generated on the effects of lithium hydroxide on the corrosion of zircaloys, even though it is a common coolant additive in PWRs, used to maintain an alkaline coolant pH which assists in the transport of crud produced on and by structural materials. [10] There have been studies at very high (4.2 molar, 300°C) [8] or moderate (.0005-1.0 molar,

340°C)[9] concentrations of LiOH on Zr-2.5 Wt Pct Nb tubing, as well as low concentration zircaloy-4 studies[10].

It appears that below a certain critical concentration of lithium hydroxide inside the oxide layer itself, there is no appreciable acceleration of the corrosion rate [10]. McDonald, et al, set this level for zircaloy-4 at 100 ppm. Over this value, the acceleration is pronounced. McDonald has reported the acceleration by a factor of almost 350 the corrosion of zircaloy-4 in 0.1 molar LiOH solution versus water at 633K. The work of Manolescu, et al [9], and Zreiba and Northwood [8] suggest similar accelerations.

Zircalloys in pure water oxidize in two regimes: the pre-transition regime, featuring cubic kinetics; and the post-transition, showing linear oxide growth with time. (A more complete discussion of oxidation kinetics appears in section 2). In lithium hydroxide solutions, however, this appears to change. McDonald, et al, and Manolescu, et al., [8,9] have found no pre-transition kinetics exist in solutions of greater than 0.1 molar LiOH. In lower concentrations, however, kinetics similar to those found in pure water exist.

Typical coolant concentrations of lithium hydroxide in pressurized water reactors range from .2 to 2 ppm

(3×10^{-5} to 3×10^{-4} moles per liter) [10], not the 0.1 molar and higher concentrations discussed above. Higher concentrations may result, however, from local boiling of coolant, especially in thick oxide or crud layers. These insulating layers cause higher rod surface temperatures, and thereby encourage boiling inside the oxide layer itself. (See figure 3 for a typical cross-section of an oxidized fuel rod clad) One possible explanation is that as the coolant boils away, the lithium hydroxide dissolved in it could be deposited on the rod surface. This could then be dissolved in the next drop of coolant that reaches the surface, producing a much higher LiOH concentration at that point on the rod surface. As this process (boiling, deposition and re-solution) repeats itself, a significant increase in the local LiOH concentration, and thus the corrosion rate, may result. McDonald et al, reported a doubling (70 -140 ppm) of the concentration inside the oxide at even fairly high LiOH concentrations and static (unheated) conditions. The increase in lithium hydroxide concentration within the oxide would be even more pronounced under heated conditions which encourage boiling.

In addition, there appears to be some synergy between temperature and concentration effects on the corrosion rate of zircaloy. McDonald, et al, found that

the corrosion acceleration was directly proportional to the concentration of lithium hydroxide held up in the oxide layer. The maximum concentration that the oxide can hold, however, appears to be temperature dependant. Therefore, not only does an increase in temperature increase oxidation rate by the kinetics discussed above, but it allows an increase in the amount of lithium hydroxide present at the oxidizing surface, accelerating the corrosion even further. Coupled with the boiling effects discussed above, the corrosion rate could increase by orders of magnitude over that expected.

Table 1 and Figure 4 show the acceleration of oxidation rate found in static autoclave tests described in a later section. The effect of increasing LiOH concentration and temperature on the oxidation rate is clearly evident. (A more complete analysis of the data is presented in section 3.4 of this report) Also note that these are tests run without a heat flux, which should increase the oxidation rate further in the TGTF.

Figure 3
Typical Fuel Rod Clad Cross-Section

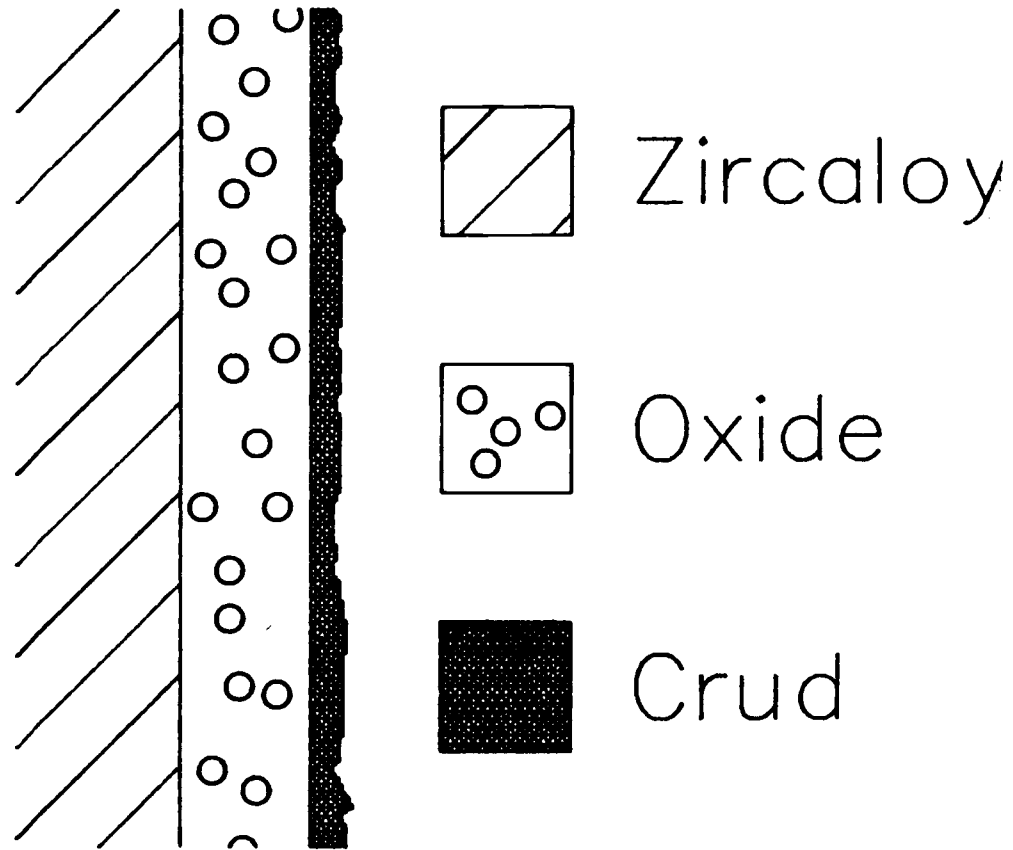


Table 1
Acceleration of Oxidation vs. Concentration

LiOH Concentration <u>moles/liter</u>	Acceleration at:		
	<u>300</u>	<u>330</u>	<u>360</u>
0.05	3.55	--	--
0.10	7.77	5.65	2.00
0.50	3.94	8.76	12.2
1.00	16.11	47.8	52.1
2.00	23.55	72.66	45.1

Acceleration of Oxidation is defined above as the ratio of the oxide growth rate at a specified concentration divided by the rate of oxidation in pure water.

Acceleration vs Concentration LiOH

300, 330, and 360°C 36 hr

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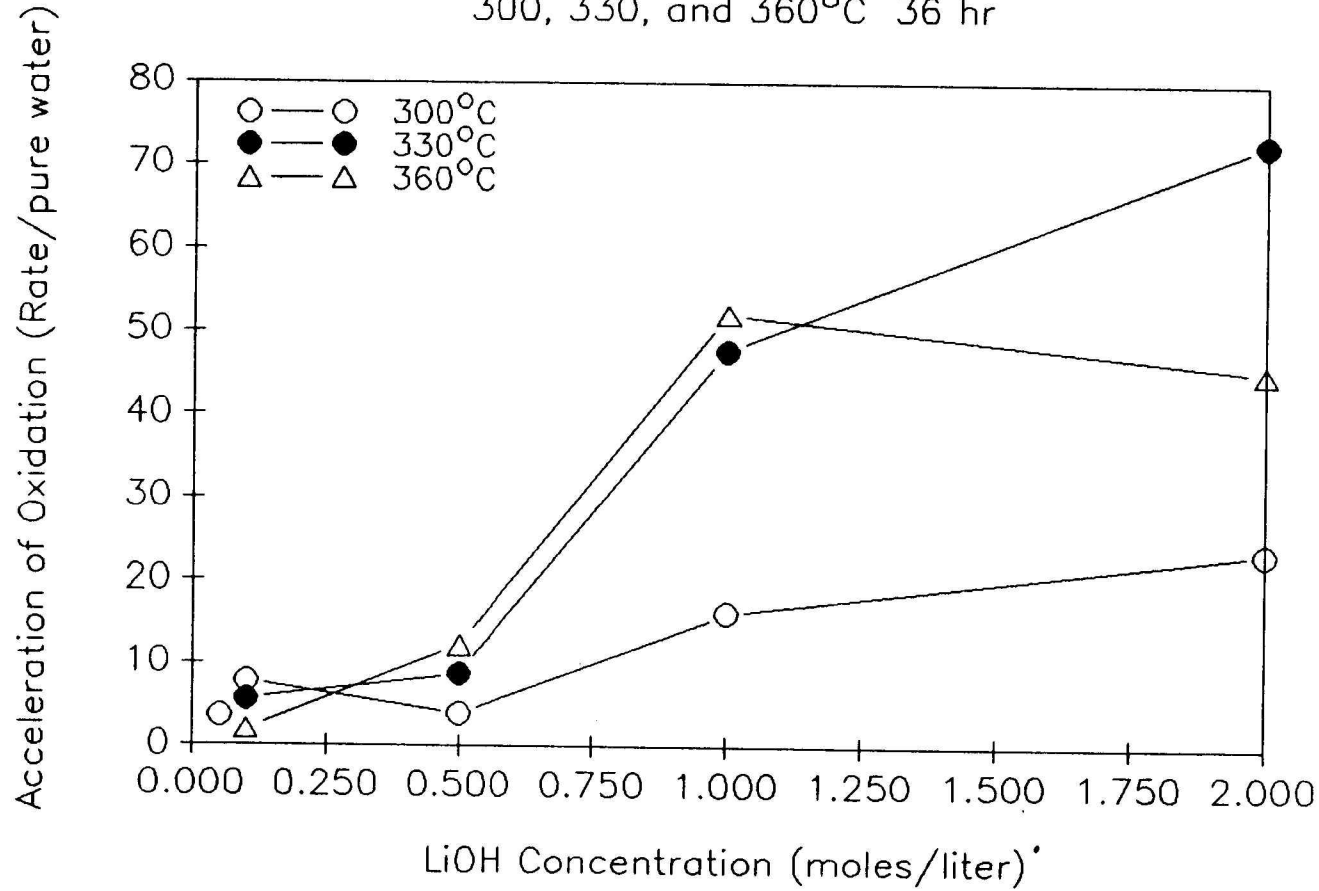


Figure 4

3.2 Models

MCDonald, et al, presented a modified Arrhenius-type relationship for concentrations lower than 0.1 molar and between 589 and 633K:

$$\ln(dw/dt) = 25.39 + 185.6[Li] - 407.4[Li]^2 - \frac{(32660 + 110540[Li])}{RT}$$

Where:

dw/dt is the post-transition corrosion rate
(mg/dm²-day)

[Li] is the LiOH concentration (moles/liter)

R is the gas constant (1.987 cal/K-mole)

T is the corrosion temperature (K)

Manloescu, Meyer and Simpson discussed corrosion rate in the form:

$$\frac{W}{A} = k_2 C^m$$

Where:

W= weight gain (mg)

A= specimen surface area (dm²)

k_2 = Proportionality constant

C= lithium hydroxide concentration
(moles/liter)

m= concentration exponent

Fitting data to this model, they found that m is approximately one, suggesting a linear concentration-corrosion relationship.

3.3 Experimental Procedure

The specimens used for static autoclave testing are zircaloy-4 tubes, cut to a length such that the surface area of the tubes was 10 cm^2 . ($.1 \text{ dm}^2$) Specimen preparation consisted two phases: first, blasting off any existing oxide layer with glass beads (propelled by compressed air), followed by pickling in a solution of hydrofluoric and nitric acids. The pickling solution dissolves surface zircaloy, giving each specimen an identical, smooth surface, free of oxide and cracks which might enhance or impede corrosion.

The specimens were placed on a stainless steel tree (see Figure 5), along with a stainless steel coupon, which was used to determine if the autoclave or any of its components might be experiencing any damage during testing.

Solutions were prepared using distilled water and crystalline lithium hydroxide monohydrate. No special stirring or agitation was necessary as LiOH is very soluble in water. In addition, the solutions were all

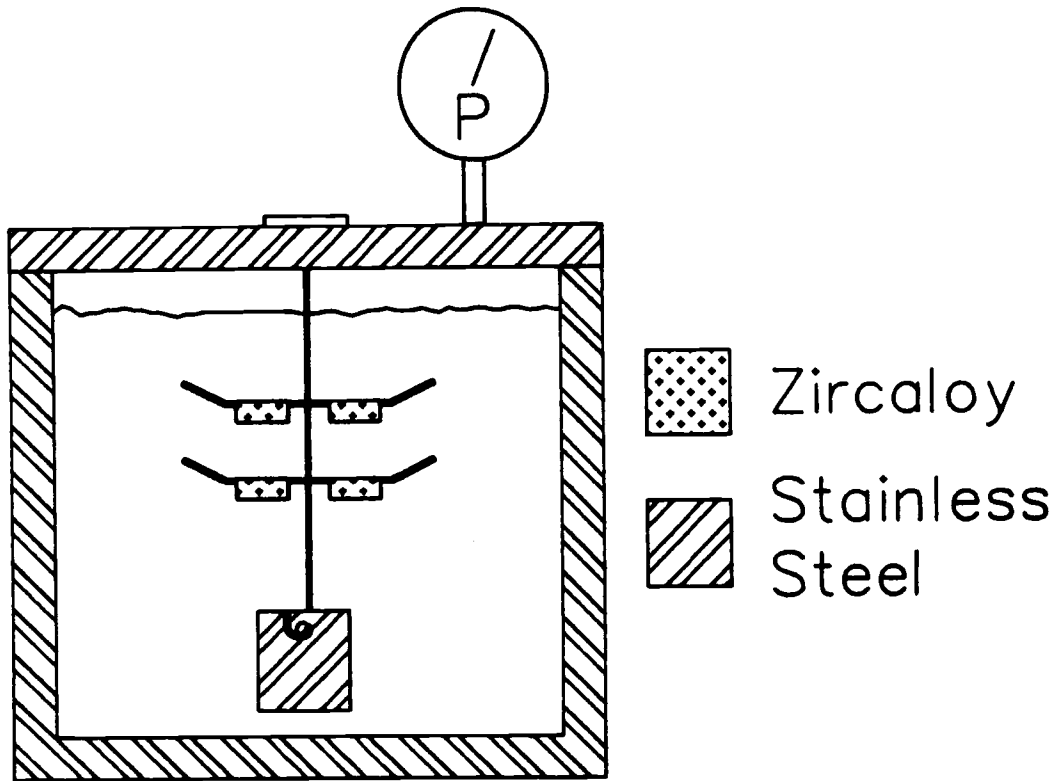


Figure 5
Experimental Apparatus

kept sub-saturated. A saturated solution would be approximately 5 molar LiOH at room temperature. The solutions were placed in a one-liter, stainless steel autoclave. The tree containing the specimens was attached directly to the autoclave lid. Pressure and temperature were monitored, with emergency systems (heater shutoff for high thermocouple temperature reading, and a burst disk for overpressurization). Although no pre-pressurization testing for leaks was conducted, leaks have not been a major difficulty. Exposure time began when the solution reached the target temperature. Time to ramp up to temperature and cool down were not considered as part of the exposure time for several reasons. Since the oxidation rate for these solutions is exponentially temperature-dependant, the heating period should not provide any significant oxidation compared to the full-temperature time. In addition, heating times were kept as short as possible (2-3 hours) in comparison to the total testing time (36 hours), so that the specimens spent as little time near (but not yet at) full temperature as possible. Long periods of time at nearly full temperature would lead to oxidation rates that appear to be higher than they are.

The specimens, upon removal from the autoclave, were rinsed thoroughly in running hot water to remove any LiOH crystals which may have formed during cooldown.

(The fluid level in the autoclave was below the upper specimens at room temperature to allow for thermal expansion for the 360°C tests.) The specimens were then air-dried, and were weighed to .1mg.

For the 300°C and 360°C tests, specimens were re-used for runs at the same temperature, with the oxide blasted off as mentioned above. In the 330°C tests, however, only two of the four samples were blasted and pickled, while the other two were left untreated. This was to measure what, if any, effects an existing oxide layer might have on the oxidation rate. All specimens thus treated were placed into a solution of higher concentration than they had been exposed to before, to mitigate the effects of any LiOH carryover in the oxide layer polluting the system.

3.4 Results

Results from the 300, 330 and 360°C tests are presented in figures 5, 6, 7 and 8. The line superimposed on them is a linear regression of the data points, to compare them with the model predicted by Manolescu, et al. [9] The data gathered to this point do not seem to support the linear hypothesis, except at high concentrations (>0.5M LiOH). In figures 9, 10, 11 and 12, McDonald's model [10] is examined. In these,

the linearity of the graphs is much greater, lending credence to McDonald's model, again at high concentrations.

Oxidation vs Concentration LiOH

300°C 36 hr

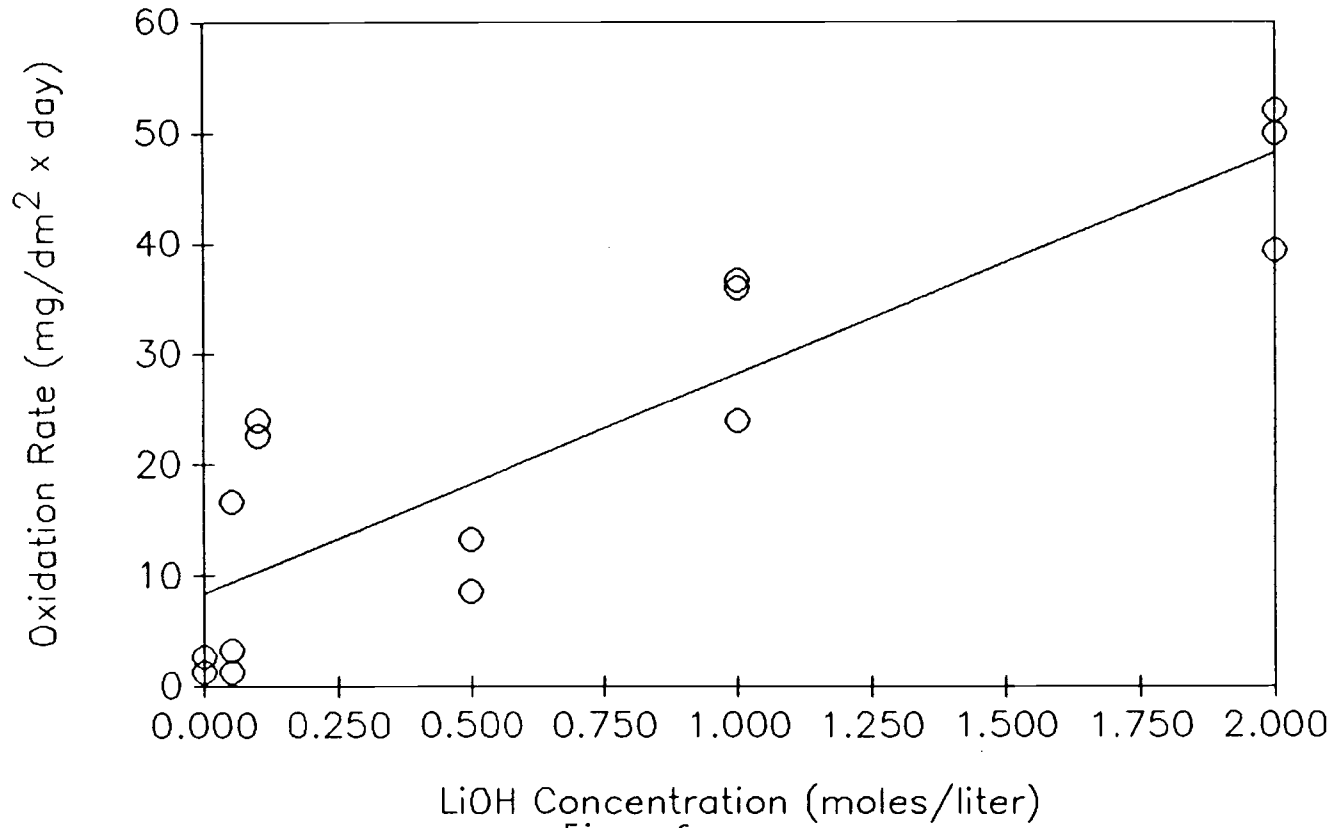


Figure 6

Oxidation vs Concentration LiOH

330°C 36 hr

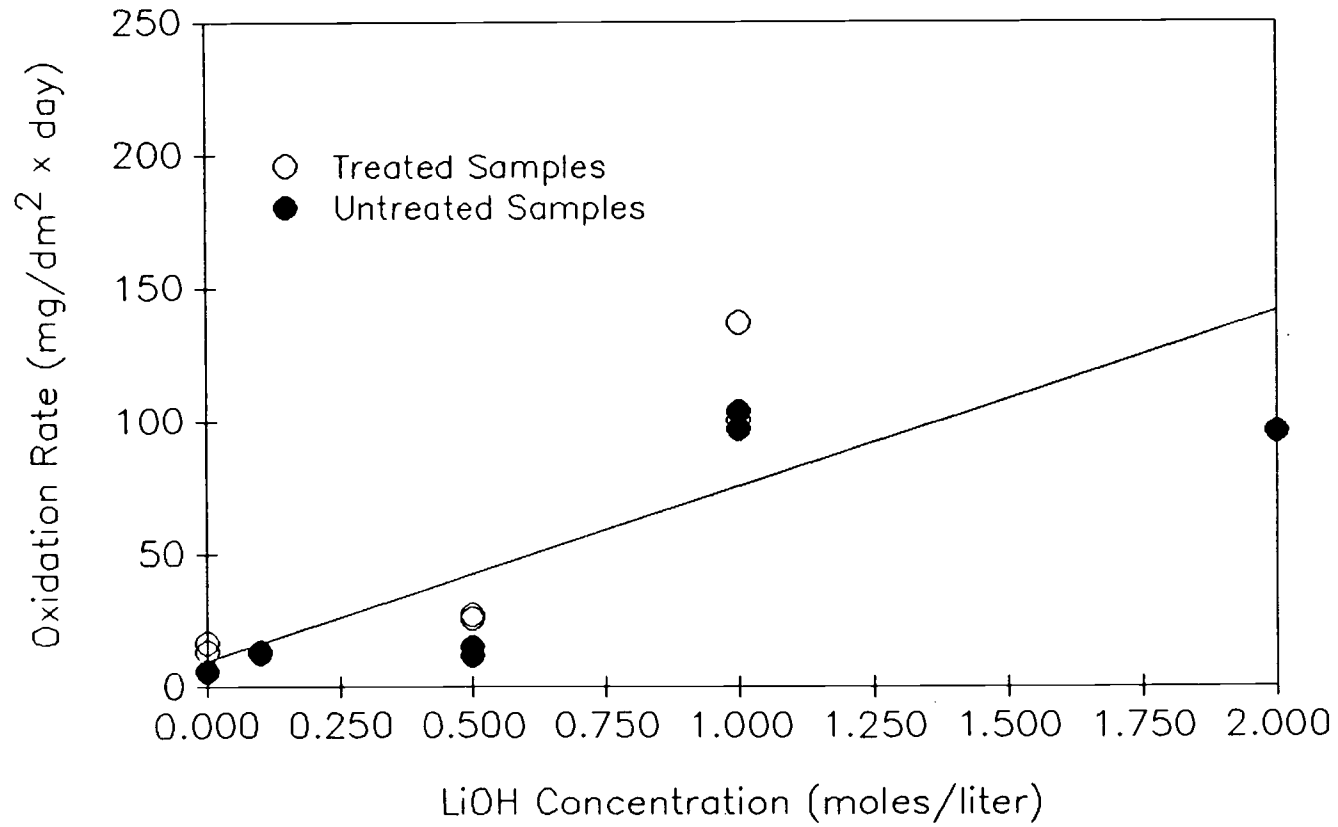


Figure 7

Oxidation vs Concentration LiOH

360°C 36 hr

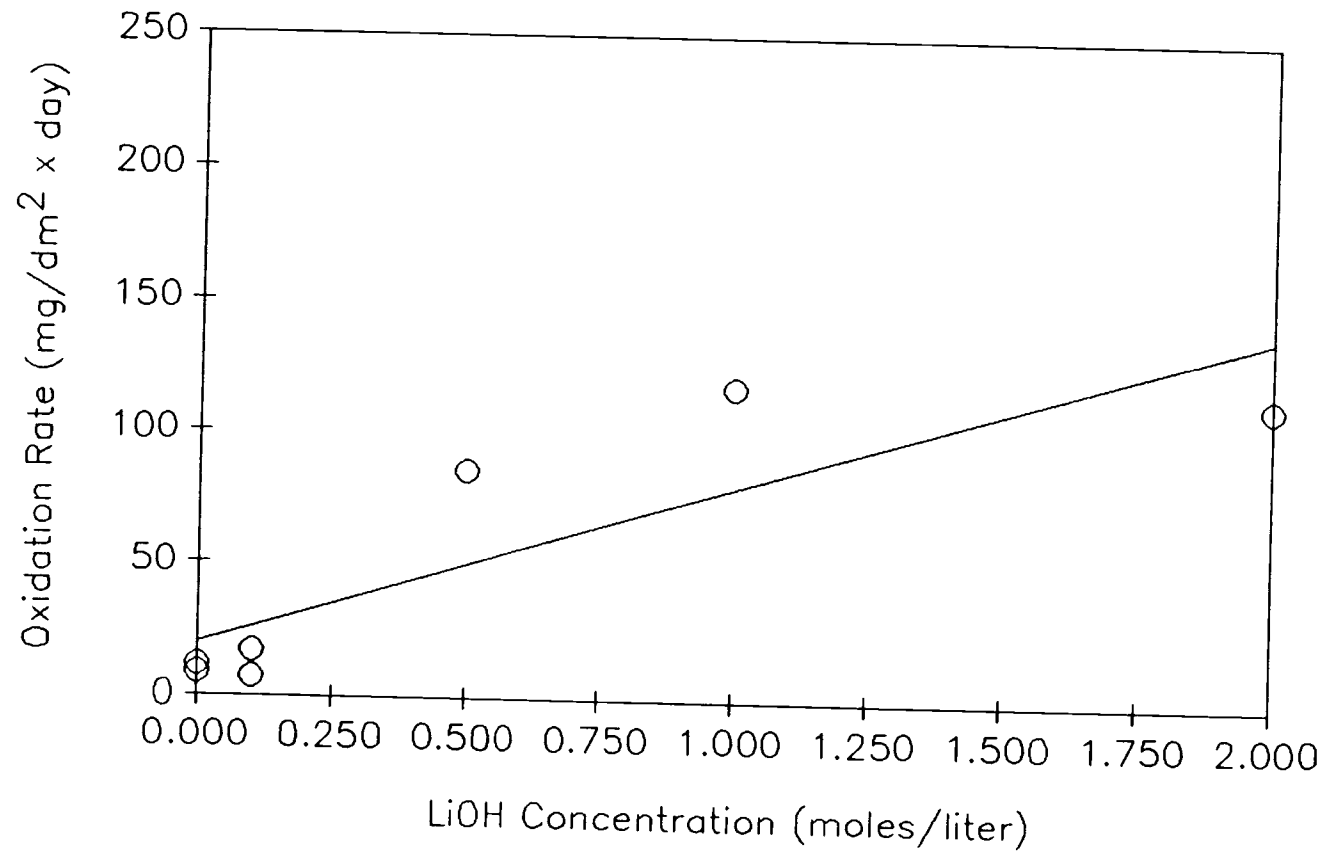


Figure 8

Oxidation vs Concentration LiOH

300, 330, and 360°C 36 hr

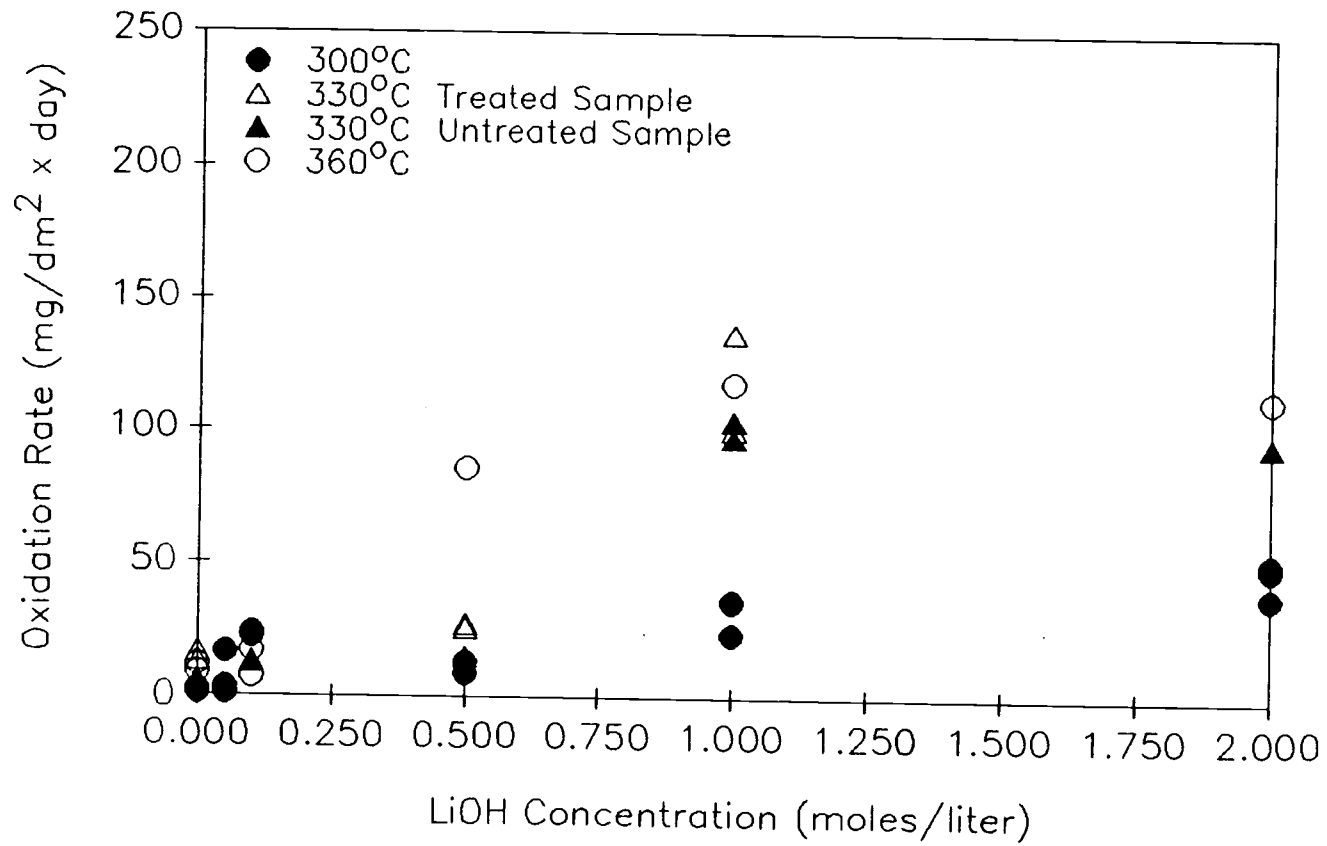


Figure 9

ln(weight gain) vs 1/T

Exploring M^cDonald's Model

0.5 M LiOH

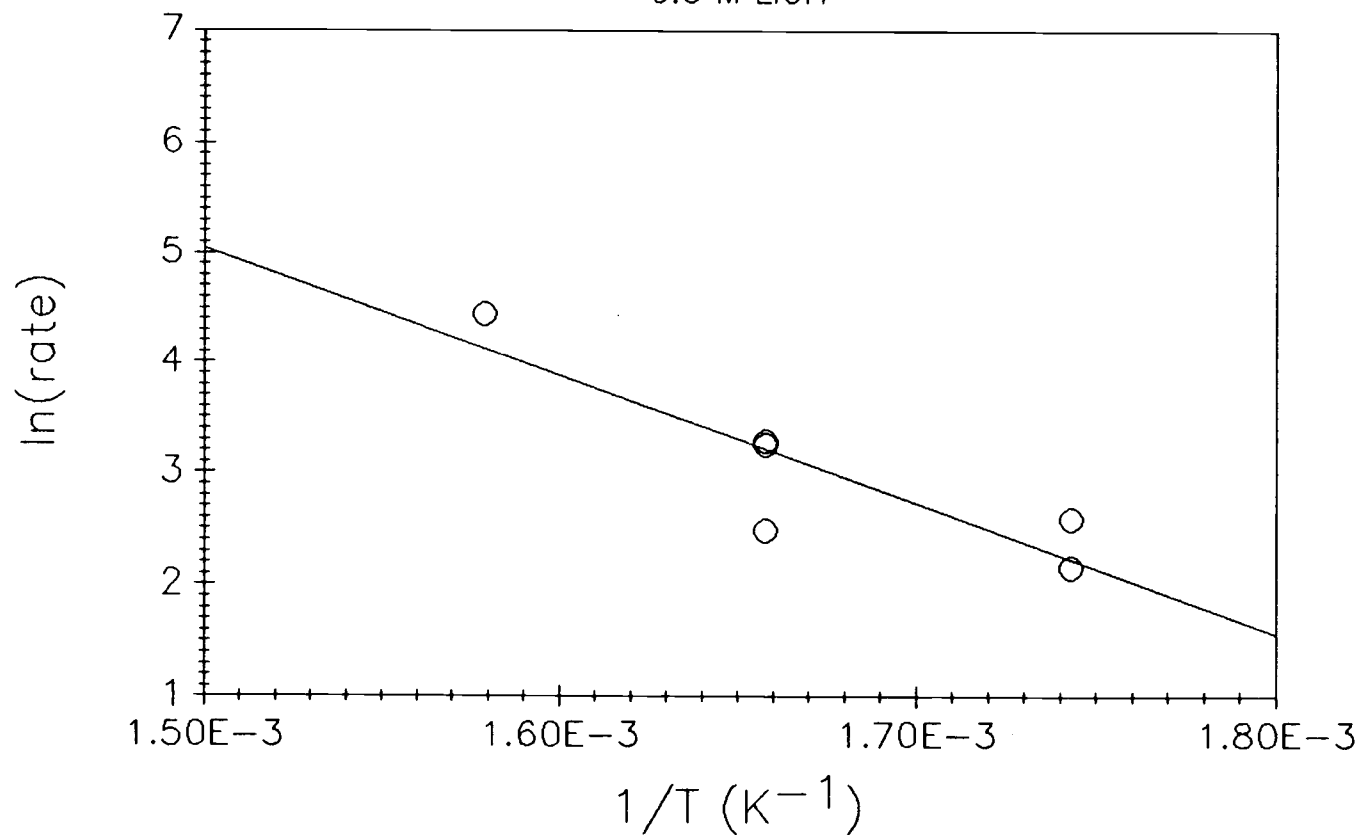


Figure 10

In(weight gain) vs 1/T

Exploring M^cDonald's Model

1.0 M LiOH

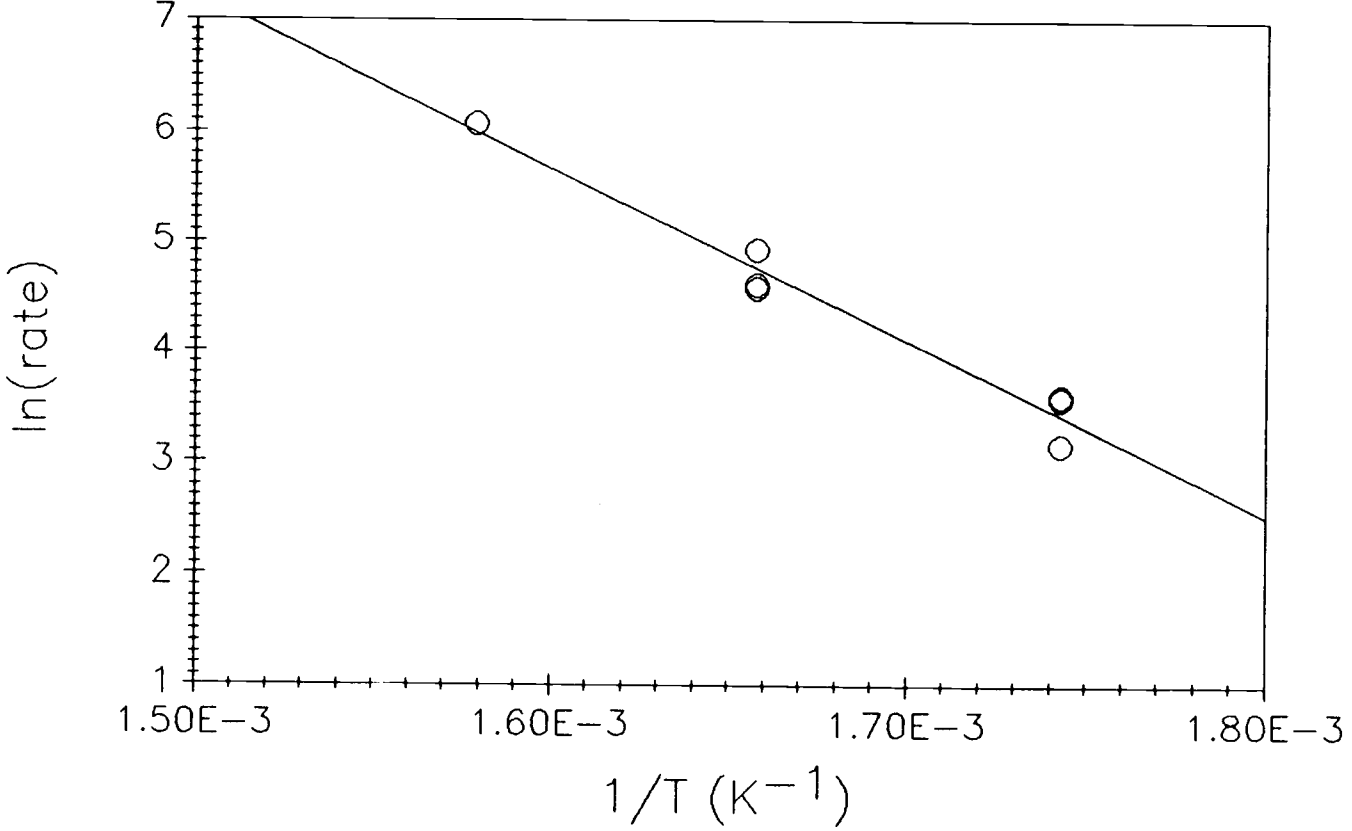


Figure 11

In(weight gain) vs 1/T

Exploring M^cDonald's Model

2.0 M LiOH

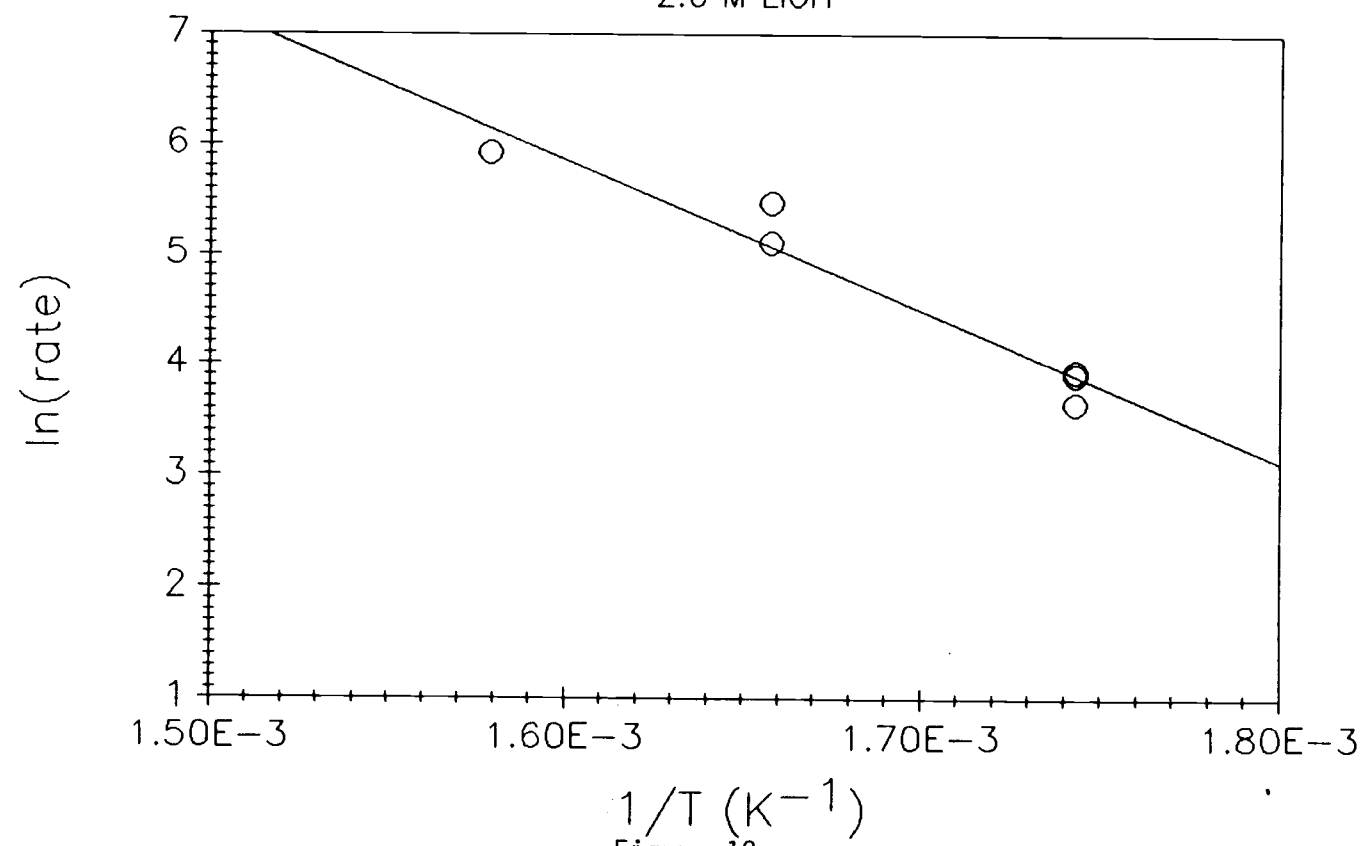


Figure 12

ln(weight gain) vs 1/T

Exploring M^cDonald's Model

0.5, 1.0, 2.0 M LiOH

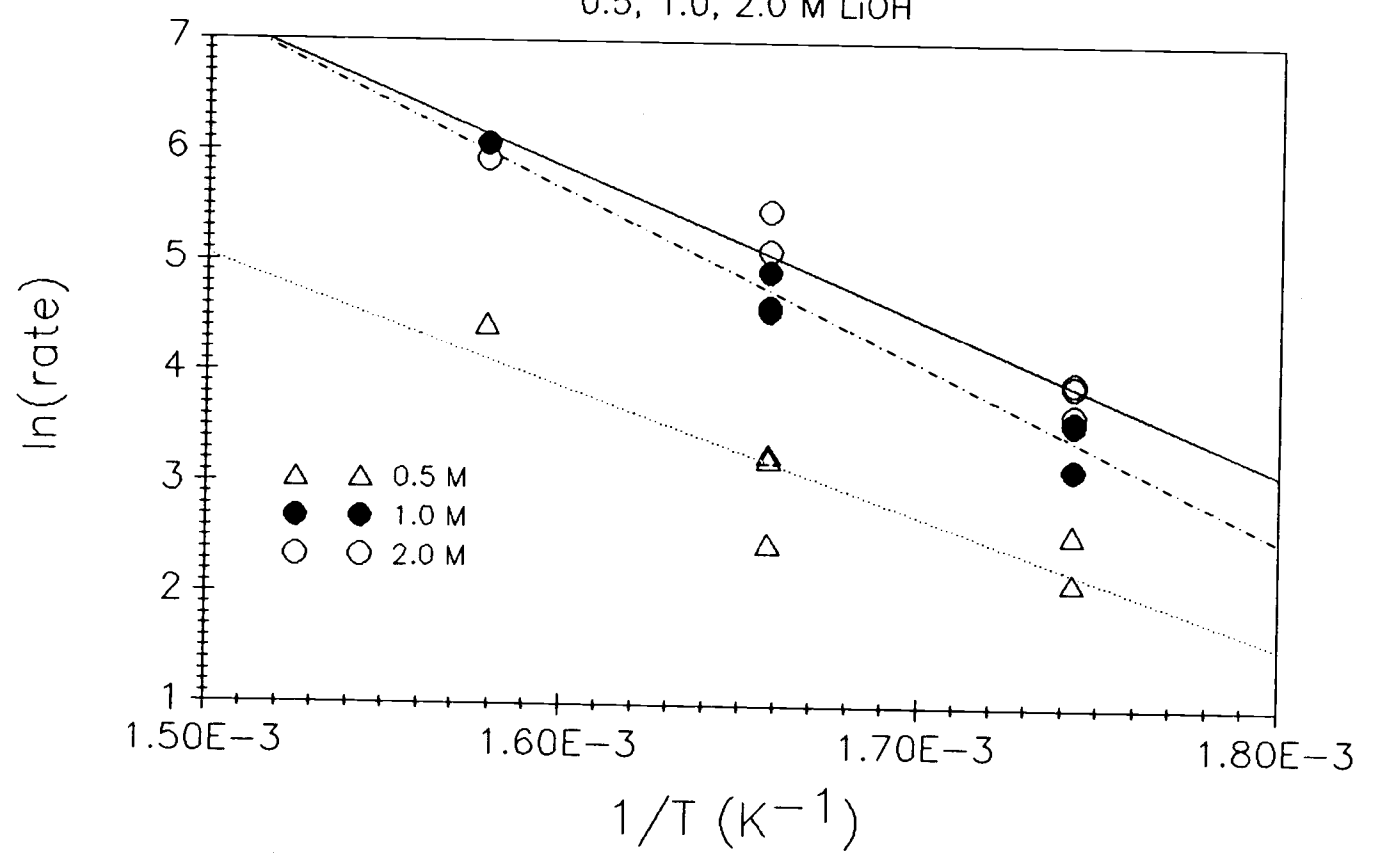


Figure 13

Unfortunately, there is a great deal of scatter in the data, especially at the lower concentrations. Experimental error, from several sources, must take most of the responsibility for this scatter. First, although the preparation of the samples is done as uniformly as possible, each sample is different. With the re-using of samples to conserve zircaloy, there is a question of whether bead blasting removes all the residual oxides, and whether repeated oxidation and blasting changes the zircaloy surface in any way. Another difficulty of bead blasting is in removing all of the oxide on the inside surface of the clad. Also, samples used many times may be developing cracks, etc, which will interfere with the results. Finally, lithium hydroxide may be penetrating the zircaloy itself, or leaching out some alloying components of the zircaloy, changing the metal, and thus the oxidation results.

The rate at which the samples are being oxidized these samples seems to make the oxide layer somewhat delicate, and handling can remove oxide from the sample, lowering the apparent weight gain. The oxide may also be spalling (flaking) off in the autoclave during cool-down, when thermal stress is present. Repetition of these experiments should improve the data, as the average weight gain from many tests can be reported, and these experimental errors can hopefully be minimized. One

final possible source of error is the short exposure time. Although 36 hour tests allowed significant oxidation to be accomplished in a reasonable period of time, the variability of the cool-down time may have been enough to introduce error into the measurements.

This is not to say that this data is useless. Several key results can be seen from these data sets. First, and most obviously, high lithium hydroxide concentrations do cause massive increases in the oxidation rate of zircaloy-4. This acceleration seems to follow the McDonald model discussed above at high concentrations. Another, unexpected discovery comes from the 330°C tests, where the untreated samples consistently oxidized more slowly than the treated samples. There are two possible explanations for this phenomenon: first, that the assumption made by McDonald and Manolescu of no pre-transition behavior at high concentrations is wrong; or, the oxide layer is slowing the movement of LiOH to the active clad surface. The second of these seems more likely, as the period of these tests is short enough that the diffusion effect could make a significant impact on the oxidation rate. At much longer exposure times, the treated and untreated samples should oxidize at the same rate.

Another unexpected discovery was made in the 360°C tests. Because of the need to provide for the thermal

expansion of water in the autoclave, the upper samples in the 360°C tests were left uncovered by fluid at room temperature. There was a large difference (six or seven times) in weight gains between samples that soaked in the cold solution and those that didn't. In fact, one test was repeated because the sample, after a 10-day soak, emerged from the autoclave with a non-uniform, "speckled" appearance, and an enormous weight gain. The mechanism for this effect has not yet been discovered.

One constant is that the linear plots seem to do better at the higher concentrations, as might be expected. At high concentrations, concentration effects tend to overwhelm any errors that may be occurring.

4.0 PRESSURIZED WATER REACTOR ZIRCALOY OXIDATION DATABASE

For this project, a database has been constructed from multiple published reports. The database, running under Microrim's R-Base System V, contains data from over 20 different sources, covering many aspects of zirconium and zircaloy oxidation. When used alone, or in concert with experimental data, the database will be used to examine various environmental effects on zirconium oxidation. It is intended that the database remain in archives at the OSU Radiation Center, with additional data added as it becomes available. With this large store of information available, the amount of research necessary for future students in this field should be reduced dramatically.

4.1 Categories in the database

Each data array in the database contains many types of information, such as: reactor data (temperature, Lithium Hydroxide, dissolved Oxygen or Hydrazine concentration, and pH); Rod data (Power and heat distribution, neutron or gamma flux, pre-filming thickness, polishing method, and whether the sample was pure zirconium or an alloy); bookkeeping data, such as rod ID number, location of measurement, and measurement

technique; oxide layer thickness; and additional notes or information not covered by the above categories. (For a complete list of categories, see Table 2) These categories may be used for many things, such as: sorting of data, choosing similar data for comparison (for example, all non-irradiated samples of a given temperature could be compared, to examine the effects of differing chemistries on oxidation rates); or determining effects of various reactor conditions on oxide layer thickness (such as comparing all oxygenated vs non-oxygenated samples).

4.2 Sources of Data

The data in the open literature section of the database comes from over twenty different sources, covering a variety of reactor and autoclave conditions. There is data from five different reactors, measuring the oxide thickness as a function of distance from the rod bottom. Other sources include a comparison of autoclave and in-reactor tests, a study on the effects of neutron irradiation on oxidation, and corrosion in a 4.2M LiOH solution (pH 12.3) (Example of references are listed in Table 3) We also have data from EPRI, containing multiple samples from several reactors comparing oxide thickness with distance from the bottom

of the rod, to show effects of flow obstruction on the oxidation of heated fuel rods.

4.3 Uses

With the data in the database, one may attempt to determine changes in the oxidation rate due to various environmental factors, such as pH or temperature. The data can be used to generate graphs to give a visual "feel" to various aspects of the data. An "instruction book" for database use is included as Appendix A. An explanation of the creation of graphs is included below.

The database project has also given experience in handling raw data, so that when data comes in from autoclave tests, the database is ready to assimilate it directly, and begin making comparisons between the raw data and the published material, as well as forming theories from the raw data itself. One particular relationship that seems to be worth looking into has been found already--the relationship between the turbulent flow caused by spacer grids and reduced oxidation levels directly downstream of the spacer. The large amount of data in the EPRI sets may prove to be valuable in this area. When spacer grid tests in the TGTF are completed, the data generated there will be

compared to existing data in the database to develop new models for this phenomenon.

Table 2
Database Categories

Database	
<u>Abbreviation</u>	<u>Definition</u>
ID#	Reference Identification Number
Burnup	Rod Burnup (MWD/MTU)
Power	Rod Power Density
ExpTime	Rod exposure time (units vary)
pH	Average Coolant pH
LiOHcon	Average Lithium Hydroxide Concentration
Oxycon	Average Coolant Oxygen Concentration
Hydrazin	Average coolant Hydrazine Concentration
Boricac	Average Boric Acid Concentration
Pre-thik	Pre-exposure Oxide Thickness
Localflx	Local Heat Flux
Aveoxithi	Average Oxide Thickness
Maxoxithi	Maximum Oxide Thickness

Table 2 (continued)

The following are all in TEXT format (e.g. "Cosine Power Distribution"), but could be made into a table within the total data table:

Pwrdist	Axial Power Distribution
Fluxloc	Local Heat Flux Distribution
CoolTdis	Axial Coolant Temperature Distribution
Neufluxd	Axial Neutron Flux Distribution
Gamfluxd	Axial Gamma Flux Distribution
CladTdis	Axial Cladding Temperature Distribution
c/ointrd	Axial Cladding/Oxide Interface Distribution
Pre-trea	Pre-exposure Treatment
Meastech	Measurement Technique Used

Table 3
Open Literature Examples

N.A. Zreiba and D.O. Northwood, Corrosion/Hydridding Behavior of Zr-2.5 wt Pct Nb Nuclear Reactor Tubing in Pressurized Lithiated Water (pH 12.3) at 300°C, American society for Metals, Vol. 7, No. 2, Sept 1985.

H.R. Peters, "Improved Characterization of Aqueous Corrosion Kinetics of Zircaloy-4," Zirconium in the Nuclear Industry: Sixth Annual Symposium, ASTM STP 824, D.G. Franklin and R.B. Adamson, Editors, American Society for Testing and Materials, 1984.

W. Burns and H.P. Maffei, "Neutron Irradiation Effects on Zircaloy-2 Corrosion and Hydrogen Pickup," Corrosion of Zirconium Alloys, ASTM STP 368, American Society for Testing and Materials.

The following are references from specific reactors. The report containing the references is:

F. Garzarolli, D. Jorde, R. Manzel, G.W. Parry, and P.G. Smerd, Review of PWR Fuel Rod Waterside Data, NP-1472, EPRI Research Project 1250-1

Table 3 (continued)

The following references were included, with the name of the reactor studied in parenthesis:

E. Hillner, "Corrosion and Hydriding Performance of Zircaloy Tubing After Extended Exposure in the Shippingport Pressurized Water Reactor," Zirconium Nuclear Applications, Philadelphia, PA, August 1, 1973, ASTM STP 551. (Shippingport)

T.W. Wallace, "EEI-Westinghouse Plutonium-Recycle Demonstration Program Progress Report, October 1973-October 1974," Westinghouse Electric Corporation, Nuclear Fuels Division, February 1975, WCAP-4167-7. (San Onofre-1)

A.A. Bauer, L.M. Lowry and J.S. Perry, "Evaluating Strength and Ductility of Irradiated Zircaloy--Task 5 Quarterly Progress Report, October through December 1976," Battelle Columbus Laboratory, January 1977. BMI-NUREG-1967. (H.B. Robinson-2)

Other reactors examined include Maine Yankee, Benzau-1, Jose Cabrera and Saxon II.

The following is an example of how to use the database to create graphs using SigmaPlot. The Database User's Manual (Appendix A) should be consulted over any doubts caused. (Note: most of these commands are much easier to use if selected from PROMPTS {see Appendix A} mode. This is the default condition when Rbase is entered from the Rbssystem menu. If the user is at the R> prompt, typing PROMPTS will supply a menu of choices, with some on-line help, as well)

Procedure:

- 1) Open the Database from Rbase

- 2) In the Look at Data part of the main menu, Use the BROWSE or SELECT commands to look through the data to find applicable sets.

- 3) Using the GATEWAY command (from file import/export), select EXPORT, and the file type (ASCII delimited is preferred, using a comma as the delimiter, since most graphing programs will read files of this type)

4) Choose the loading conditions for the data (for example, ID# EQ 8, Burnup LT 40, etc.)

5) The program will then begin creating the file. When prompted, supply the path and file name. (It may be useful to supply the path of your graphing program, such as C:\sigmaplo\filename, so that the data goes directly to the directory where it will be used)

6) Exit Rbase (Hit Escape until a menu featuring EXIT as a command appears, typically 2 or 3 ESCapes) and enter the graphing program (SigmaPlot, for example), and use the newly created file as an input data file therein.

7) In SigmaPlot, choose Disk from the main menu, and get data from the Disk menu. you will be prompted for the file name and type (ASCII delimited, what the delimiting character is, etc.)

8) The data files may also be edited with FRED, or any other text editor. Be sure not to change the way the data is stored (in other words, don't remove quotation marks, commas, etc)

5.0 CONCLUSIONS

The study of the oxidation of zircaloy in light water has been examined in three separate projects within this thesis: the theory and models of pure water oxidation, comparison of models with data in high concentration LiOH environments, and the construction and implementation of a database of oxidation results published elsewhere. These projects are all interrelated, and all have been geared towards problems and solutions for the Thermal Gradient Test Facility (TGTF) at Teledyne Wah Chang, Albany. Conclusions and possible future efforts for each:

The literature review and model examination of light water oxidation of zircaloy is complete. The models may be used to examine data in the database, and develop new models for various environmental factors. In addition, any pure-water oxidation in the TGTF will be used to develop new models, based on the models discussed in section 2, for zircaloy samples oxidizing under heat flux and flow conditions.

The construction of the database is complete. The database itself is an ongoing entity. As new data is received, it will be added to that already residing in the database, to provide a powerful resource for corrosion researchers at OSU in the future.

The examination of accelerated oxidation of zircaloy-4 in lithium hydroxide is ongoing, inasmuch as it has yet to be attempted in the TGTF. The strong correlation between high LiOH concentration and high corrosion rates has been demonstrated, and possible mechanisms for enhancing concentration in heated systems has been examined. Comparison of published models with the data generated in the static autoclave tests shows these models to be valid at high LiOH concentrations. (>0.5 moles/liter) Several possible sources of experimental error have been examined, and recognition of these may help avoid similar errors in the TGTF experiments. In comparing acceleration rates versus safety concerns, further static autoclave tests (and TGTF tests) should be run at 330°C. Although oxidation occurs more rapidly at 360°C, the high saturation pressure of water (>2500 psi), and the proximity to the critical temperature of water (375°C) present enough of a safety hazard that the lower temperature should be used. If the additional acceleration of oxide rate is

necessary, however, 360°C tests may be used, if strict temperature control is maintained. The static autoclaves have been operated at 360°C without failure thus far, and without damage to the autoclave itself.

The ultimate expression of this project is the operation of the TGTF under high concentration LiOH conditions, to measure the oxidation rates of a heated rod under flowing conditions, and the effects that oxide layer has on the interior temperatures of the mock fuel rod. This thesis lays the groundwork for the continuation of the TGTF project, and its future utility.

6.0 REFERENCES

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[4] Stehle, H., Kaden, W. and Manzel, R., "External Corrosion of Cladding in PWRs", Nuclear Engineering and Design, 1975.

[5] T.D. Pyecha, G.M.Bain, W.A.McInteer, and C.H.Pharm, "Waterside corrosion of PWR fuel rods Through Burnups of 50,000 MWD/MTU", Light Water Reactor Fuel Performance, DOE/34130--1, April 1985.

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[10] S.G. McDonald, G.P. Sabol, and K.D. Sheppard, "Effect of Lithium Hydroxide on the Corrosion Behavior of Zircaloy-4," Zirconium in the Nuclear Industry, Sixth International Symposium, ASTM STP 824, American society for testing and Materials, 1984.

APPENDIX

APPENDIX A

An R:Base Users Manual
for use with R:Base System V
and the databases at the OSU Radiation Center
Room RC-E102

by
Jim VanWinkle
as a part of
The Zirconium Oxidation Project

Dr. A.C. Klein, advisor

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Disclaimer: This manual is for use with R:Base System V, by Microrim. It is intended for use with the databases of published data (both open literature and EPRI proprietary) set up by Jim VanWinkle on the computers at the Radiation Center, OSU. It should not be construed to be the definitive word on R:Base. For additional information, see the various R:Base system manuals.

The Basics

Prerequisites: Using the databases does not require any previous computer experience. Knowledge of the Disk Operating System, DOS, is helpful, but not vital. It is fairly difficult to destroy data accidentally, but until familiar with the system, the novice user should just use the LEARN database, which has been set up for teaching purposes.

Notation: For those unfamiliar with some of the shorthand, any key which is bracketed [] is to be held down while another is hit. For example, the shortcut for capital 'F' is [Shift]-f. Other keys which are used similarly are the Ctrl and Alt keys, located on the lower left side of the AT keyboard. Also, the user will

often be prompted to hit the <Enter> key. This is the Return key, often labeled with a bent arrow.

Starting Up

- The programs used are on the hard disk, internal to the computer, so no floppy disks are necessary, unless transferring data from one computer to another. In this case, the Import/Export section of this manual should be consulted.

- Make sure any printers, plotters, etc. to be used are hooked up to the computer and turned on.

- Turn on the computer and monitor. It will take a few moments for the machine to do a memory test and run some internal programs.

- At the C:> prompt, type 'cd rbfiles <Enter>'. The computer should provide a prompt that looks like this:

```
C:\rbfiles>
```

- Type 'Rbsystem <Enter>' This starts the R:Base System V. A menu of choices should appear.

- Use the cursor (arrow) keys to move down the menu to highlight "R:BASE" Hit <Enter>

- R:BASE will give a number of databases to choose from. Pick the one desired with the cursor keys and strike <Enter>

- The command OPEN <Database Name> will appear with a menu of choices. Strike <Enter> to execute. The computer is now in R:BASE, using the database selected. If assigned a password (Many databases have password protection to prevent unwanted tampering or viewing of data), use the cursor to highlight "R:BASE Environment" and select it using the <enter> key. At the menu, choose "User". Respond with the assigned password at the prompt.

- The remainder of this report is composed of two parts. The first is a description of the commands used in R:Base. The second part is an example of using a database; entering, examining, editing data, and exporting data to a file for use by, for example, a graphics program.

Using R:Base

Before discussing the commands used in R:Base, some mention of terminology must be made. The terms used in this work of most interest are, from the largest to the smallest: database, table, column, variable.

Variables are single pieces of information. It may have many forms: A date, time, dollar amount, integer, real or double precision number, or even a string of text.

Columns are just that, vertical columns of related data. All data are listed under a column name.

Tables are groups of columns of data. Usually, all data in a table is related.

Databases contain a number of tables. While all of the data in a table can be accessed at once, a database may be examined only one table at a time.

On the RC-E102 computer, there a special database has been set up called LEARN. It contains only one table, EXP1, which stands for experiment 1. This table contains four columns of data: Run#(Integer),

Time(Real), Velocity(Double), and Notes(Text, maximum length 40 characters). Use of this database is discussed at the end of this report.

Prompt Mode: R:Base has an easy-to-use user interface, called Prompt mode. With this mode, all decisions for a particular command are presented in a menu form, making selecting options much easier. If R:Base is entered from other than the Rbsystem menu, R> prompt will appear. At this point, type PROMPTS <Enter>, and a menu of choices will be presented. If RBase was started from the rbsystem menu, PROMPTS mode is entered automatically. The commands discussed hereafter are grouped together just as they are in the Prompts menus. All of these commands are available from the R> prompt, but all of the conditions for the command, which can be quite long and complex, must be supplied by the user. For the uninitiated, PROMPTS mode is recommended.

The next section of the report concerns the R:Base commands. They are put in more or less the order of importance for the beginning user. An example of the commands listed:

APPEND TABLE1 to TABLE2 WHERE (Conditions)

This command 'tacks' a table named TABLE2 to the end of TABLE1, subject to conditions selected by the user. An example of typical conditions would be:

```
WHERE ID# EQ 2
```

This adds only those rows of data where the variable ID# is equal to 2.

The allowed conditions:

EQ	Equal to the number given
NE	Not equal to the number given
GE	Greater than <u>or</u> equal to the number given
GT	Greater than the number given
LE	Less than <u>or</u> equal to the number given
LT	Less than the number given
EXISTS	The data is not the R:Base null character, -0-
FAILS	The data is the null (Does not exist)

R:Base fills all unentered data with the -0- character, so don't be alarmed if partial tables are peppered with -0-s.

Data can also be sorted during display or output.

When prompted, select the variable or variables to sort the rows of data. If more than one column name is selected, the data is sorted by the data in the first column chosen first, then by the second. For Example:
If the data is:

Col1	Col2
1	4
1	2
3	2
2	1
3	4

Sorted by Col1, Col2:

Col1	Col2
1	2
1	4
2	1
3	2
3	4

Sorted by Col2, Col1

Col1	Col2
2	1
1	2
3	2
1	4
3	4

If no columns are picked to sort, the data is displayed in the order it was entered.

R:Base Commands

Starting/Finishing

These commands are used at the beginning and end of the Rbase session.

-OPEN (database name)

Opens a new database for use. A database is closed automatically in four cases: A new database is opened, the CLOSE command is executed, the EXIT command is executed, or a new database is defined.

-EXIT

This closes the database, and exits RBase. Follow the menus supplied.

LOOK AT DATA

These commands allow the user to examine, but not alter, data in the selected database, as well as perform some elementary analysis.

```
-SELECT (Column names) FROM (Table) SORTED BY (column  
name/names) WHERE (conditions)
```

Select displays data from a table. This command will show the data in the selected columns once through, one screen at a time, with no scrolling backwards allowed. It is useful for small amounts of data, when a general idea of what sort of data is in the table is required.

```
-BROWSE (Column names) FROM (Table) SORTED BY (Column  
name/names) WHERE (Conditions)
```

Browse is similar to Select, but it allows scrolling through the data in table form. Use the cursor keys to scroll left, right, and down the data table, and up the last 50 lines. To move right or left, the cursor keys do not work. Use TAB to move right, and [shift]-TAB to move left. This is a good command for seriously examining data without printing it out. It allows a slow study, and limited recall of the upper part of the table.

-COMPUTE (column name) AS (operation, listed below) FROM
(table) WHERE (conditions)

This command allows calculations on a column of
data within a table. The operations are:

AVE	Computes the average
COUNT	Determines the number of entries in the column for particular values
MAXIMUM	Gives the maximum value in the column
MINIMUM	Gives the minimum value in the column
ROWS	Calculates the number of rows in the table
STDEV	Computes the Standard Deviation of the data in the column
SUM	Totals the data in the column
VARIANCE	Computes the variance of the data

Of course, most of these commands are only useful
for data types REAL, INTEGER, DOUBLE, or CURRENCY.

-TALLY (column name) FROM (table) WHERE (conditions)

Tally counts the number of items in a column that are identical. Then it displays each unique value and the number of times it appears. This is useful to get a rough idea of how much data is in a table, or to get the range of data therein.

-CROSSTAB (operation) (column name 3) FOR (column name1)
BY (column name 2) FROM (table) WHERE (conditions)

-or-

-CROSSTAB (column name 1) BY (column name2) FROM
(table) WHERE (conditions)

CROSSTAB is used to count unique occurrences of pairs of data in two tables. This information is sorted and displayed. The first command line gives the command for using these pairs to choose data in column name 3 to perform the arithmetic operations from COMPUTE. For example, in the OXIDE database, the user may look for identical exposure times and temperatures, and calculate the average oxide thickness of those samples.

-LIST (keyword, below)

This function allows listing various information about the database being used. The allowed keywords and their uses are:

COLUMNS	List all column definitions in the database
DATABASES	List all databases in the current directory
FORMS	All form names for the database
REPORTS	All report names defined for the database
RULES	The database rules
TABLES	Lists the names of all tables in the database, with the number of columns in each table
VIEWS	All the views in the database

Most of these are not used by the beginning user. For more information, see the R:Base manuals.

-VIEW

This is not an elementary command, and not covered in this work.

ADD DATA

This series of commands allows the introduction of new data into the database from file or keyboard.

-APPEND (table1) TO (table2) WHERE (conditions)

This copies rows from table2 to the end of table1. This is useful if sets of data have been entered separately, but all of the data must be examined together.

-ENTER (form name)

This allows the use of an already created form to enter data. It is not an elementary command.

-INPUT (filename or KEYBOARD)

Allows entry of commands or data from an ASCII file instead of the keyboard. Not the recommended way to add data. INPUT KEYBOARD puts restores normal keyboard use. Not an elementary command.

-LOAD (Table name) WITH PROMPTS USING (column names)

This allows addition of data to the selected database using the keyboard. The WITH PROMPTS statement causes the computer to display the name of the column and the data type to be entered. This is the method used to enter the data into the tables found in the OSU computer.

EDIT DATA

These commands allow modification of already entered data, either single variables, or groups.

-CHANGE (column name) to (value or expression) IN (table) WHERE (conditions)

This command allows the values of an entire column to be changed. For example, all of the null values in a column may be changed to zero. Or, for example, all of the variables in a column may be multiplied by a constant, such as in a units change. (e.g. multiply all values in a column named time by 60 to change from hours to minutes)

-DELETE DUPLICATES FROM (table)

-or-

-DELETE ROWS FROM (table) WHERE (condition)

The DELETE command removes data from a table. The first command removes all duplicate rows of data in a table. The second allows removal of data in accordance with the conditions specified. BE VERY CAREFUL WITH THIS COMMAND. A user could accidentally destroy large amounts of data very quickly with DELETE. Double check every bit of information in the command line when using DELETE. Please do not use it in the OXIDE or OXID1 databases at all.

-EDIT (column names or ALL) FROM (table) SORTED BY (columns) WHERE (conditions)

This is the standard editing function in R:Base. It allows scrolling up and down through the data, changing data by simply typing the new values in the place of the old. When editing is complete, strike the Escape key. Edit looks much like BROWSE, but in Edit, information may be changed, not just examined. Like BROWSE, use TAB and [Shift]-TAB to move left and right through the data.

-REMOVE (keyword)

Allows deletion of columns, forms, reports, rules, views or tables from the open database. This is another dangerous command, as entire tables of data may be removed. Do not use on the OXIDE or OXID1 databases.

IMPORT/EXPORT

These commands allow data to be transferred from machine to machine, or even from program to program. Data may be taken from RBase, and manipulated by spreadsheet or graphics program.

-GATEWAY

This accesses the FileGateway program, allowing the user to send or receive data to or from a file on disk. There are several formats available:

ASCII delimited

ASCII fixed field

Lotus 1-2-3 or Symphony (WKS, WK1, or WRK)

dBase II, III, or III+ (DBF) (Import only)

pfs:FILE (Import only)

DIF (Visicalc or other programs)

SYLK (Multiplan or other)

When GATEWAY is invoked, Prompts will ask for the database name, table name, columns to export, and conditions. The GATEWAY program has an excellent HELP system, which appears on the menu, but it should not be needed. The preferred format is ASCII delimited files, using a comma as the delimiting character, which is useful if using SIGMAPLOT to plot the data. An example of using GATEWAY is included in the last part of this report.

-UNLOAD (ALL, DATA, or STRUCTURE) FOR (table) USING (columns) SORTED BY (columns) WHERE conditions

This command copies the data and structure of the database to the device specified by the OUTPUT command (screen, file, or printer). This does not in any way change the data in the database. This is not an elementary command.

-INPUT

See INPUT under the ADD DATA section.

PRINT DATA

Allows output of data to line printer.

-OUTPUT (Screen, Printer, or file name) WITH (Screen, Printer, BOTH, file name)

Routes the output of the program to the screen, a printer, a file, or any combination of the above. The default condition is Screen. This can be useful to print out the output of the SELECT command.

-PRINT (report name) SORTED BY (columns) WHERE (conditions)

This is used to print out reports created by the report processor, and is not an elementary topic.

-SELECT, TALLY, COMPUTE, CROSSTAB, and LIST

Can all be found in the LOOK AT DATA SECTION

-DISPLAY

Is not an elementary command discussed here.

-TYPE (file name)

This displays an ASCII file, similar to the DOS Type command

RELATIONAL OPERATIONS

These commands allow manipulation of tables and columns within the database to create new tables and columns.

-APPEND

See Append under ADD DATA

-INTERSECT (table1) WITH (table2) FORMING (table3) USING (column names)

Intersect takes two tables and compares selected columns, creating a new table out of the data the first two tables share. For example, in the OXIDE database, one could combine data where the Temperatures were equal.

```
-JOIN (table1) USING (column name 1) WITH (table2) USING  
(column name 2) FORMING (table3) WHERE (conditions)
```

This command creates a new table (table3), from table1 and table2, where the specified columns in those two tables meet the conditions specified. For example, a new table could be created from two others where the data in column 1 is larger than that in column 2.

```
-PROJECT (table2) FROM (table1) USING (column names)  
SORTED BY (column names) WHERE (conditions)
```

This creates a new table (table2) out of data from an old table (table1). It can, therefore, be a complete copy of the old table, or only a subset. This command could be used to create a new table using only data from a particular data range in the old table.

```
-SUBTRACT (table1) from (table2) FORMING (table3) USING  
(column names)
```

This forms a new table from the data in table2 that do not match data in table1.

-UNION (table1) WITH (table2) FORMING (table3) USING
(column names)

This builds a new table from two separate tables which have at least one column with the same name.

DATABASE MAINTENANCE

These commands include means to back up a database, and general "housekeeping" for the disk.

-PACK

When data is deleted from the database, the structure of the database does not differentiate the new empty spaces from data. The PACK command causes the database to remove non-used rows from the structure, saving disk space. This command is usually not necessary unless massive deletions occur. The database should be PACKed occasionally, especially after heavy use, or when disk space becomes sparse.

-RELOAD

RELOAD duplicates a database without copying the unused space occupied by dead data sectors. It also

puts the new database on contiguous disk space, to speed access.

-BACKUP (ALL, DATA, or STRUCTURE) FOR (table) USING
(column names) SORTED BY (column names) WHERE
(conditions)

BACKUP allows an extra copy of a database to be kept for security reasons. Use the command BACKUP ALL to back the entire database up as often as is necessary to insure minimal data loss. With over 4 Meg of data, the OSU database backups are kept very up-to-date, always after any major additions or deletions.

-RESTORE

Brings back a database backed up using the BACKUP command.

-UNLOAD

See UNLOAD under the IMPORT/EXPORT heading

DATA INPUT/DATA OUTPUT

Under this heading are several commands already covered in earlier sections. See the alphabetical listings at the end of this report to find individual commands.

RBASE ENVIRONMENT

These commands are the "background" for the RBase sessions. They are for setting default parameters, and are seldom changed during normal operation.

-SET

SET allows the user to set defaults for many parameters in the database. This is not an elementary topic, so please see the R:BASE manuals for more information

-SHOW

This command shows the status of system parameters set using the SET command. Again, this is not an elementary topic.

-LIST

See LIST under LOOK AT DATA

-USER (password)

The USER command identifies persons having clearance to read or modify certain tables, or entire databases. If assigned a password, use the USER command at the beginning of the session of using R:BASE.

CREATING A DATABASE

Allows construction of a new, empty database.

-RBDEFINE

This is a menu-driven database creation routine, with its own on-line help. This command was used to create all databases available on the OSU computer.

-DEFINE

This allows the user to specify the structure for a given database, which can be a new or existing database. Not an elementary topic.

MODIFYING A DATABASE

These commands are all beyond the scope of this report. In Prompts mode, each has its description given in a very short form, so a user could learn the use of each either by reading these short descriptions or getting the R:BASE manuals.

EDIT AN ASCII FILE

-RBEDIT (file name)

This program can be used to edit short files without having to leave R:BASE. The R:BASE users manual contains the commands for advanced editing using RBEDIT.

DOS COMMANDS

The DOS commands available within R:BASE are: CHDRV, CHKDSK, COPY, DIR, ERASE, MKDIR, RMDIR, RENAME, TYPE. For information on each of these, consult the DOS manual.

ALL COMMANDS

This menu is an alphabetical list of all the commands available while using R:BASE. Descriptions of each appear above.

This ends the discussion of R:BASE commands. Any additional questions are best left for the manuals of operation for R:BASE. The remainder of the report is a short discussion of using R:BASE with a sample database named LEARN.

WORKING WITH R:BASE

On the AT in the Radiation Center, Room E-102, a sample database named LEARN has been installed for instructional purposes. It has one table, named EXP1, containing the columns Run#, Time, Velocity, and Notes. Here are a few things to try with it. Feel free to experiment with this database. Make add data to the tables, edit it, what have you. Try most of the commands given above in the commands section. But mostly, one should try to get the "feel" of how RBase works.

Some Thing to Do:

- Start up the computer and R:Base using the instructions at the beginning of this report.

- Open the Database named LEARN

- Look at the data using the SELECT and BROWSE commands. See what changing the conditions and SORTED BY does.

- Use the TALLY command to get an Idea of what kind of data exists in the table

- Using the EDIT command, make some changes in the data.

- Change all the times given from seconds to minutes by multiplying by 60 using the CHANGE command.

- Using the LOAD command, add data to the end of the table. Remember to use PROMPTS to ease loading.

- Use the GATEWAY to send out (export) data to a file. Try to give each file created a unique name, and try to remember to remove them at the end of the R:BASE session. Use RBEDIT to look at the file just created. Experiment with ASCII delimited and fixed formats see any differences.

- Experiment. The most important commands to be familiar with are in the LOOK AT, ADD, EDIT, and IMPORT/EXPORT DATA categories. These are the bread and butter of the use of R:BASE.

Remember, the PROMPTS mode is a much easier way of executing these commands. If you find yourself not at a menu, don't panic. At the R> prompt, type PROMPTS. If not, hit the Escape key. A menu of choices should appear. Simply choose the proper one to continue.