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EXAMINE THE FUEL SIZE EFFECT ON NUCLEAR POWER REACTOR SAFETY

A.I. Oludare[1], M.N. Agu,[2] A.M. Umar,[3] S.O. Adedayo[4], O. E. Omolara[5] and L.N. Okafor[6]
[1]Nigerian Defence Academy, Department of Physics, Kaduna
[2] Nigeria Atomic Energy Commission, Abuja
[3] Energy Commission of Nigeria, Department of Nuclear Science & Technology, Abuja
[4] National Open University of Nigeria, Department of Information Technology, Abuja
[5] Ahmadu Bello Universities, Department of Mathematics, Zaria, Nigeria
[6]Nigerian Defence Academy, Department of Mathematics and Computer Science, Kaduna

ABSTRACT: *The mass of fuel in the operating reactor could contribute to the safety of the reactor. To investigate the cooling problem of the fuel, safety margin test was conducted on design decay heat and design volume of the fuel in the reactor core. Linear Regression Analysis Techniques was applied on some typical Water-Cooled Reactor Design (WCRD) models. The results of the statistical analysis on these types of nuclear reactor models reveals that the WCRD models promises stability under application of small size of uranium (fuel) at 9g and below than large size of uranium (fuel) at 12g and above. Meanwhile, at 9g of fuel element the reactor seems to be most stable and safer as the regression plot was optimized. The safety margin prediction of 0.62% was validated for a typical WCRD model as an advantage over the current 5.1% challenging problem for plant engineers to predict the safety margin limit. The implication of this research effort to Nigeria's nuclear power project is discussed.*

KEYWORDS: Nuclear fuel size effect, high temperature, reactor safety, water-cooled reactor design model, safety factor, Ỳ, optimization, stability margin in reactor designs

INTRODUCTION

Large uranium (fuel) size could contribute to the causes of pressure built-up within reactor core of nuclear power plant but small size of uranium will provide low power density reactor that will minimize heat generation in the reactor core and also disallow fuel melting that may produce decay heat in the core assemblies and degenerated to hydrogen built-up that can make reactor to fail. As identified in some nuclear accident like the case of Fukushima Daiichi Nuclear accident, the fuel became critical as it could not cool down [1].

The overheating of nuclear fuel in the reactor core could lead to temperature rise and gradual pressure built-up in the system. "Removal of residual heat could not be assured at Daiichi nuclear plant". Nuclear fuel is any material that can be consumed to derive nuclear energy or Nuclear fuel is a material that can be 'burned' by nuclear fission or fusion to derive nuclear energy. The nuclear fuel can swell during use; this is because of effects such as fission gas formation in the fuel and the damage which occurs to the lattice of the solid. The fission gases accumulate in the void that forms in the center of a fuel pellet as burnup increases. As the void forms, the once-cylindrical pellet degrades into pieces. The swelling of the fuel pellet can cause pellet-cladding interaction when it thermally expands to the inside of the cladding tubing. The swollen fuel pellet imposes mechanical stresses upon the cladding. The fuel cladding is the first layer of protection around the nuclear fuel and is designed to protect the fuel from corrosion that would spread fuel material throughout the reactor coolant circuit. In most reactors it takes the form of a sealed metallic or ceramic layer. It also serves to trap fission products, especially ones that are gaseous at the temperatures reached within the reactor, such as krypton, xenon and iodine. Cladding does not constitute shielding, and must be developed such that it absorbs as little radiation as possible. For this reason, materials such as magnesium and zirconium are used for their low neutron capture cross sections.

As swollen fuel pellet imposes mechanical stresses upon the cladding, the fuel expands on heating the core of the pellet more than the rim. Because of the thermal stress thus formed the fuel cracks, the cracks tend to go from the center to the edge in a star shaped pattern. The cracking of the fuel has an effect on the release of radioactivity from fuel both under accident conditions and also when the spent fuel is used as the final disposal form. The cracking increases the surface area of the fuel which increases the rate at which fission products can leave the fuel. The temperature of the fuel varies as a function of the distance from the center to the rim. At distance *d* from the center the temperature (T_d) is described by the equation where ρ is the power density (W m^{-3}) and K_f is the thermal conductivity.

$T_d = T_{Rim} + \rho\,(r_{pellet}^2 - d^2)\,(4\,K_f)^{-1}$ ……………………………………..(1)

When the nuclear fuel increases in temperature, the rapid motion of the atoms in the fuel causes an effect known as Doppler broadening. When thermal motion causes a particle to move towards the observer, the emitted radiation will be shifted to a higher frequency. Likewise, when the emitter moves away, the frequency will be lowered. For non-relativistic thermal velocities, the Doppler shift in frequency will be**:**

$$f = f_0\left(1+\frac{v}{c}\right) \quad \text{……………………………………………………………….(2)}$$

where f is the observed frequency, f_0 is the rest frequency, v is the velocity of the emitter towards the observer, and c is the speed of light.
Since there is a distribution of speeds both toward and away from the observer in any volume element of the radiating body, the net effect will be to broaden the observed line.
If $P_v(v)dv$ is the fraction of particles with velocity component v to $v+dv$ along a line of sight, then the corresponding distribution of the frequencies is

$$P_f(f)df = P_v(v_f)\frac{dv}{df}df \quad \text{,…………………………………………………….(3)}$$

where

$v_f = c\left(\frac{f}{f_0}-1\right)$ is the velocity towards the observer corresponding to the shift of the rest frequency f_0 to f.
Therefore,

$$P_f(f)df = \frac{c}{f_0}P_v\left(c\left(\frac{f}{f_0}-1\right)\right)df \quad \text{.……………………………(4)}$$

We can also express the broadening in terms of the wavelength λ. Recalling that in the non-relativistic limit $\frac{\lambda-\lambda_0}{\lambda_0} \approx -\frac{f-f_0}{f_0}$, we obtain

$$P_\lambda(\lambda)d\lambda = \frac{c}{\lambda_0}P_v\left(c\left(1-\frac{\lambda}{\lambda_0}\right)\right)d\lambda.$$
…………………………(5)

In the case of the thermal Doppler broadening, the velocity distribution is given by the Maxwell distribution

$$P_v(v)dv = \sqrt{\frac{m}{2\pi kT}}\,\exp\left(-\frac{mv^2}{2kT}\right)dv$$
,…………………………………(6)

where,
m is the mass of the emitting particle, T is the temperature and k is the Boltzmann constant.

Then,

$$P_f(f)df = \left(\frac{c}{f_0}\right)\sqrt{\frac{m}{2\pi kT}}\,\exp\left(-\frac{m\left[c\left(\frac{f}{f_0}-1\right)\right]^2}{2kT}\right)df$$
,…………(7)

We can simplify this expression as

$$P_f(f)df = \sqrt{\frac{mc^2}{2\pi kT{f_0}^2}}\,\exp\left(-\frac{mc^2\left(f-f_0\right)^2}{2kT{f_0}^2}\right)df$$
,……………………(8)

which we immediately recognize as a Gaussian profile with the standard deviation

$$\sigma_f = \sqrt{\frac{kT}{mc^2}}f_0$$
,…………………………………………………………(9)

and full width at half maximum (FWHM)

$$\Delta f_{\mathrm{FWHM}} = \sqrt{\frac{8kT\ln 2}{mc^2}}f_0.$$
,……………………………………(10)

The fuel then sees a wider range of relative neutron speeds. Uranium-238, which forms the bulk of the uranium in the reactor, is much more likely to absorb fast or epithermal neutrons at higher temperatures. This reduces the number of neutrons available to cause fission, and reduces the power of the reactor. Doppler broadening therefore creates a negative feedback because as fuel temperature increases, reactor power decreases. All reactors have reactivity feedback mechanisms, except some gas reactor such as pebble-bed reactor which is designed so that this effect is very strong and does not depend on any kind of machinery or moving parts.

There have been several reports and analysis on the safety of reactors with respect to nuclear fuel these includes; “Nuclear Fuel Safety Criteria Technical Review”[2], “Nuclear fuel behaviour under reactivity-initiated accident (RIA) conditions - State-of-the-art report,”[3], “Current Trends in Nuclear Fuel for Power Reactors,”[4]. “Review of Fuel Failures in Water

Cooled Reactors,"[5] "Nuclear Fuel Behaviour in Loss-of-Coolant Accident Conditions,"[6] "Failure of high burnup fuels under reactivity-initiated accident conditions,"[7] and "PWR fuel behavior in RIA-simulating experiment at high temperature" [8]. These accidents may perhaps be as a result of design concept process of BWR and PWR(which could involve novel technologies) that have inherent risk of failure in operation and were not well studied/understood. In avoiding such accidents the industry has been very successful. In over 14,500 cumulative reactor-years of commercial operation in 32 countries, there have been only three major accidents to nuclear power plants - Three Mile Island, Chernobyl, and Fukushima. In physics risk can be measure in terms of frequency and magnitude. As in other industries, the design and operation of nuclear power plants aims to minimise the likelihood of accidents, and avoid major human consequences when they occur.

Failure may be recognized by measures of risks which include performance, design fault, obsolete components, wrong application, human errors and accident. These risks can be defined and quantified as the product of the probability of an occurrence of failure and a measure of the consequence of that failure. Since the objective of engineering is to design and build things to meet requirements, apart from cost implication, it is important to consider risk along with performance, and technology selections made during concept design. Engineering council guidance on risk for the engineering profession defined "Engineering Risk" as "the chance of incurring a loss or gain by investing in an engineering project". Similar definitions are given by Modarres, Molak and Blanchard, that risk is a measure of the potential loss occurred due to natural or human activities.

In this work, Ordinary Least Square (OLS) methodology, which is largely used in nuclear industry for modeling safety, is employed. Some related previous works on the application of regression analysis technique include**:** "Stochastic Modeling of Deterioration in Nuclear Power Plants Components"[9],"Regression Approach to a Simple Physics Problem"[10], "Best estimate safety analysis for nuclear power plants uncertainty evaluation"[11]. Others are, "Estimation of the power peaking factor in a nuclear reactor using support vector machines and uncertainty analysis"[12], "Regression analysis of gross domestic product and its factors in Lithuania,"[13] "An Approach for validating actinide and fission product burnup credit criticality safety analyses isotopic composition predictions"[14], "Extending the application range of a fuel performance code from normal operating to design basis accident conditions,"[15] and "Investigating the Effect of Loss-of-Pressure-Control on the Stability of Water-Cooled Reactor Design Models,"[16].

The Research Objectives
To apply the linear regression technique on water-cooled reactor design models such as BWR and PWR design models for the determination of their Safety Margin in terms of applicable fuel size or fuel volume within the operating reactor core and to carry out analysis of the reactor stability on the rate of fuel size or fuel application.

The Research Motivation
The purpose of this work is to assist countries wishing to include nuclear energy for the generation of electricity, like Nigeria, to secure a reactor that is better and safe. Also, the studies intended to provide guidance in developing practical catalytic materials for power generation reactor and to help researchers make appropriate recommendation for Nigeria nuclear energy proposition as one of the solutions to Nigeria energy crisis. Moreover, the study is to provide a good, novel approach and method for multi-objective decision-making

based on six dissimilar objectives attributes**:** evolving technology, effectiveness, efficiency, cost, safety and failure. Furthermore, this is to help Nigeria meet its international obligations to use nuclear technology for peaceful means. Finally, the achievement is to make worldwide contribution to knowledge.

RESEARCH DESIGN/APPROACH

Theory and experiment have shown that for a water-cooled reactor, the volume of fuel determines the heat or decay heat within reactor core. Therefore, the mass of the fuel plays significant role in the safety of the reactor during operation in preventing overheating of reactor and reactor meltdown during accident. Hence, in this work, an assessment of the rise in fuel temperature in the reactor is considered of a typical boiling/pressurized water reactor designs. More specifically, the studies will concentrate on technical factors that limit the achievement of higher burn-up of fuel, such as the fuel size mechanical interaction. Detailed investigations of fuel behaviour under reactor accident conditions are also included.
The research approach involves adjusting the parameters of a model function to best fit a data set. A simple data set consists of *n* points (data pairs) (x_i, y_i), *i* = 1, ..., *n*, where x_i is an independent variable and y_i is a dependent variable whose value is found by observation. The model function has the form *f* (*x*,β), where the *m* adjustable parameters are held in the vector β. The goal is to find the parameter values for the model which "best" fits the data. The least squares method finds its optimum when the sum, *S*, of squared residuals

$$S = \sum_{i=1}^{n} {r_i}^2$$

is a minimum……………………………………………………………(11)

Nuclear Fuel Types

The vast majority of nuclear fuel used today consists of uranium dioxide pellets contained in a sealed tube of zirconium alloy to make a fuel rod. There are many variations in the way the rods are supported in assemblies or bundles for use in the reactor, and improvements in both the fuel rod and assembly structure have been continuous. The Table 1 lists typical features of the fuel used in power producing reactors today. 1 Zircaloy-2 and -4 are alloys of zirconium with about 1.5% tin as the main alloying element. Magnox alloy is magnesium with about 1% aluminium or zirconium. Both E110 and E635 are alloys of zirconium with about 1% niobium.

Table 1. Fuel Features

Reactor type	**Fuel material**	**Fuel rod cladding1**	**Typical Assembly**	**Enrichment**
AGR	UO2	Stainless steel	Circular array of pins in graphite sleeve	2 - 4%
BWR	UO2	Zircaloy-2	Square array	Up to 4.95%
Magnox	U metal	Magnox alloy	-	Natural
RBMK	UO2	E110, E635	Circular array	Up to 2.8%
PHWR	UO2	Zircaloy-4	Circular bundle	Natural
PWR	UO2	Zircaloy-4	Square array	Up to 4.95%
WWER	UO2	E110, E635	Hexagonal array	Up to 4.95%

The Tables 2 presented the values of design fuel input parameters in an operating reactor. For each of these different designs, a linear regression analysis technique was applied using statistical power analysis software, NCSS.

Table 2: Input data for safety margin against fuel size in a typical water-cooled reactor.
Source : [17]

Nos. of trial (j)	Fuel size in Mass (g)	Heat Generated ^{o}C
1	2.8	200
2	3.5	270
3	4.2	300
4	5.0	440
5	5.7	480
6	6.0	520
7	7.4	600
8	8.3	760
9	9.0	900
10	10.6	1050
11	11.0	1100
12	**12.0**	**1200**

RESULTS AND ANALYSES

1. Water-Cooled Reactor Design (WCRD)

The results of the application of the linear regression analysis of the data in Table 1 for a typical BWR and PWR are presented as follows:

(i) Empirical Expression for Safety Factor, Ỳ

Examine the effect of fuel size on the Stability and Safety of the nuclear reactor during operation. The data obtained in Table 1 which represents a typical parameter for Water-Cooled Reactor Design (WCRD) was modified in order to obtain the best fit for the model. The new conceptual fuel design for reactor operation could optimize the performance of the water-cooled reactor.

The linear regression model equation to be solved is given by:

$$\grave{Y} = B_0 + B_1 X_j + e_j \qquad (12)$$

where,
B_0 is an intercept, B_1 is the slope, X_j is the rate of increase in fuel volume
e_j = error or residual,
$j = 1,2,3,\ldots,k$
and k is the last term.

Empirical Expression for Safety Factor, Ỳ for Normal Pressure Reading

The model empirical expression is the equation of the straight line relating heat in the reactor and the volume of fuel in the reactor as a measure of safety factor estimated as:

$$\grave{Y} = (139.3887) + (110.9289)*(X_j) + e_j \quad (13)$$

- the equation (13) is the estimated model or predicted

where,

$\grave{Y}$ = Dependent Variable (decay fuel heat),
Intercept = 139.3887,
Slope = 110.9289,
X = Independent Variable (the volume or mass of the fuel),
e = error or residual,
j = 1,2,3,…,12 and
12 is the last term of trial.

The Figure 1 shows the linear regression plot section of residual of heat or fuel temperature and volume of the fuel effect on the reactor

(ii) Linear regression plot section

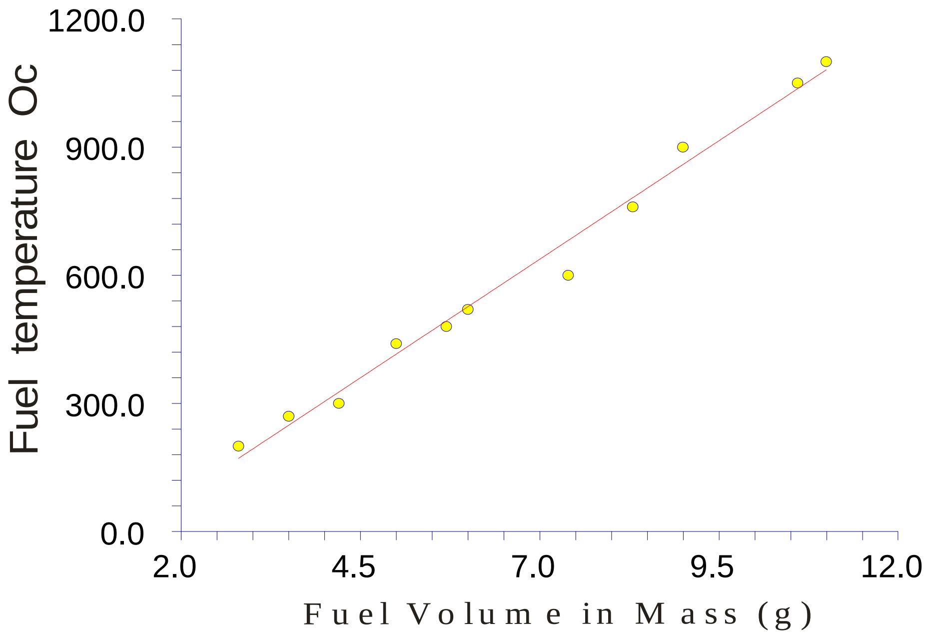

Figure 1: Fuel effect on the stability of operating reactor

(iii) F-test Result

Table 3: Summary of F-test Statistical Data

Parameter	**Value**
Dependent Variable	Ỳ (Decay heat or temperature)
Independent Variable	X (fuel volume)
Intercept(B_0)	139.3887
Slope(B_1)	110.9289
R-Squared	0.9875
Correlation	0.9938
Mean Square Error (MSE)	1.347137×10^{-3}
Coefficient of Variation	0.0610
Square Root of MSE	36.70336

- In Table 3 the R^2 value of 0.9875 indicates that 98.75% of the variation in Y has been explained by the X variables.

- Siegel (2002, P 577) has shown that R^2 can be used to test the validity of a model since it can be tested directly in this manner. If R^2 calculated value is smaller than the critical value in the R^2 table then the model is not significance in that case we accept H_o. But, if the R^2 value is larger for the calculated value, then the model is significant at the given significant level. The critical value for n-12 and k-1 is 0.673 or 67.3%. Thus the model equation is significant at the given significant level of 5%.

- The correlation at 0.9938 shows that the model has significant level of acceptance and could be of significant practical application. Accounting for 0.62 safety margin

- The value $1.347137\text{x } 10^{-3}$ for the mean square error (MSE) indicates that the error is minimized at optimal. This value $3.4976\text{x } 10^{-3}$ shows that the error is high in the test.

The Table 4 highlights descriptive statistics section results

Table 4: Descriptive Statistics Section

Parameter	**Dependent**	**Independent**
Variable	Heat (^{0}c)	Fuel (g)
Count	12	12
Mean	601.8182	6.6818
Standard Deviation	311.9878	2.7949
Minimum	200.0000	2.8000
Maximum	1100.0000	11.0000

The Table 5 is the regression estimation section results that show the least-squares estimates of the intercept and slope followed by the corresponding standard errors, confidence intervals, and hypothesis tests. These results are based on several assumptions that are validated before they are used.

Table 5: Regression Estimation Section

Parameter	**Intercept B(0)**	**Slope B(1)**
Regression Coefficients	-139.3887	110.9289
Lower 95% Confidence Limit	-206.9666	101.5348
Upper 95% Confidence Limit	-71.8107	120.3231
Standard Error	29.8732	4.1527
Standardized Coefficient	0.0000	0.9938
T-Value	-4.6660	26.7122
Prob Level (T-Test)	0.0012	0.0000
Reject H0 (Alpha = 0.0500)	Yes	0.0000
Power (Alpha = 0.0500)	0.9849	1.0000
Regression of Y on X	-139.3887	110.9289
Inverse Regression from X on Y	-148.7376	112.3281
Orthogonal Regression of Y and X	-148.7369	112.3280

In Table 6 the analysis of variance shows that the F-Ratio testing whether the slope is zero, the degrees of freedom, and the mean square error. The mean square error, which estimates the variance of the residuals, was used extensively in the calculation of hypothesis tests and confidence intervals.

Table 6: Analysis of Variance Section

Source	**DF**	**Sum of Squares**	**Mean Squares**	**F-Ratio**	**Prob Level**	**Power(5%)**
Intercept	1	3984036	3984036			
Slope	1	961239.4	961239.4	713.5426	0.0000	1.0000
Error	9	12124.23	1347.137			
Adj. Total	10	973363.6	97336.37			
Total	12	4957400				
S = Square Root(1347.137) = 36.70336						

In Table 7 Anderson Darling method confirms the rejection of H_0 at 20% level of significance but all of the above methods agreed that H_0 Should not be rejected at 5% level of significance. Hence the normality assumption is satisfied as one of the assumptions of the Linear Regression Analysis is that the variance of the error variable δ^2 has to be constant.

Table 7: Tests of Assumptions Section

Assumption/Test Residuals follow Normal Distribution?	**Test Value**	**Prob Level**	**Is the Assumption Reasonable at the 20% or 0.2000 Level of Significance?**
Shapiro Wilk	0.8921	0.147784	No
Anderson Darling	0.4847	0.227540	Yes
D'Agostino Skewness	-1.9311	0.053468	No
D'Agostino Kurtosis	1.4457	0.148249	No
D'Agostino Omnibus	5.8194	0.054492	No
Constant Residual Variance?			
Modified Levene Test	0.6445	0.442780	Yes
Relationship is a Straight Line?			
Lack of Linear Fit F(0, 0) Test	0.0000	0.000000	No

Notes:
A 'Yes' means there is not enough evidence to make this assumption seem unreasonable.
A 'No' means that the assumption is not reasonable

(iv) Residual Plots Section

The plot section is used as further check on the validity of the model to satisfy all the assumptions of the linear regression analysis.
Amir D. Aczel (2002, P528) have stated that the normality assumption can be checked by the use of plot of errors against the predicted values of the dependent variable against each of the independent variable and against time (the order of selection of the data points) and on a probability scale.
The diagnostic plot for linear regression analysis is a scatter plot of the prediction errors or residuals against predicted values and is used to decide whether there is any problem in the data at hand Siegel F (2002, p.578).

The Figure 2 is for the plot of errors against the order to selection of the data points (e = 1,2,…,12). Although the order of selection was not used as a variable in the mode, the plot reveal whether order of selection of the data points should have been included as one of the variables in our regression model. This plot shows no particular pattern in the error as the period increases or decreases and the residuals appear to be randomly distributed about their mean zero, indicating independence. The residuals are randomly distributed with no pattern and with equal variance as volume of fuel increases.

Note:
1. Residual = original value for heat (Y) minors predicted value for heat, Ỳ
2. Count = the design number (design 1, 2, 3, …, 12)

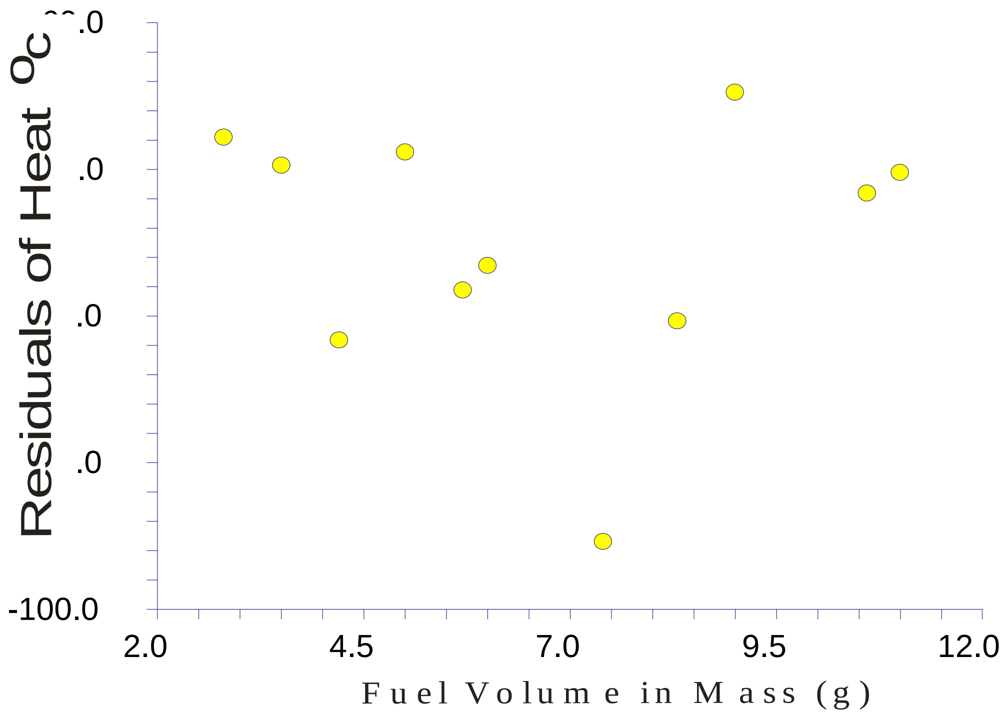

Figure 2**:** Residuals of Heat (^{0}C) versus Fuel (g)

Figure 3 shows the histogram of residuals of error (e_t) and this is nearly skewed to the right but the software used indicated that the plot is normal.

While Figure 4 is the result on plot graph of experimental errors. The residuals are perfectly normally distributed as most of the error terms align themselves along the diagonal straight line with some error terms outside the arc above and below the diagonal line. This further indicates that the estimated model is valid.

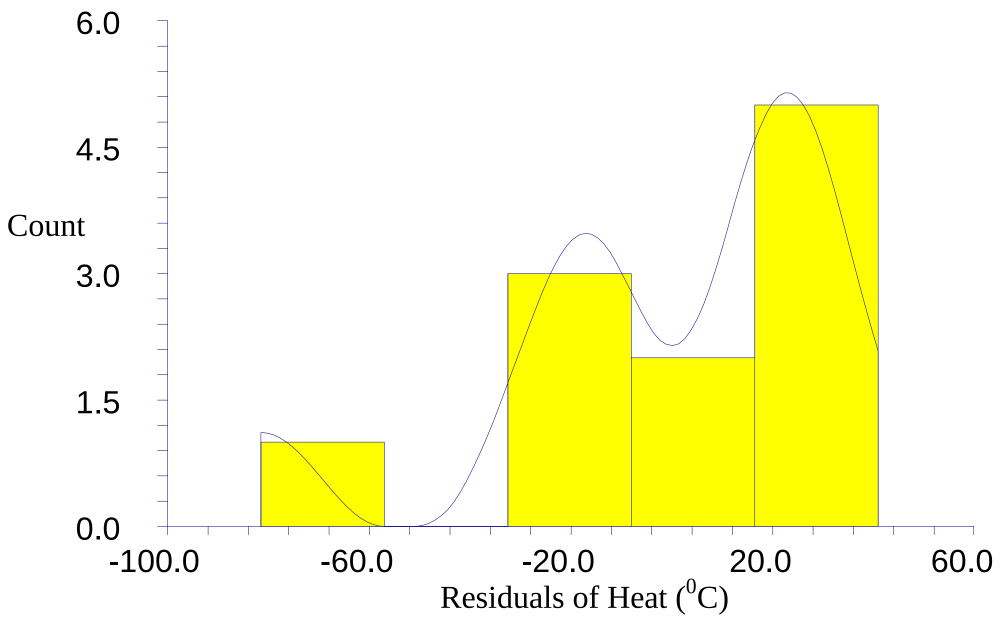

Figure 3**:** Histogram of Residuals of Heat (^{0}C)

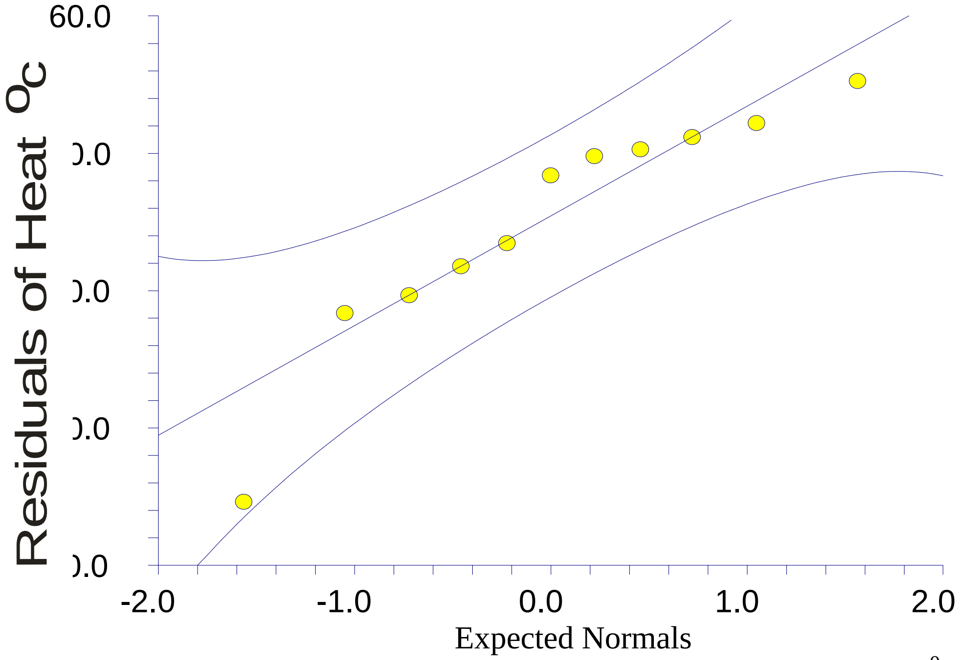

Figure 4**:** Normal Probability Plot of Residuals of Heat (^{0}C)

SUMMARY/CONCLUSION

The equation of the straight line relating heat in the reactor as against the volume of fuel in the reactor is estimated as**:**

$\grave{Y} = (139.3887) + (110.9289)*(X_j) + e_j$	- this is the estimated model or predicted

(i) This is the model equation that could be applied to make predictions of the safety factor on these types of reactor design models as relating to the heat in the reactor and the volume of fuel in the reactor.
(ii) The empirical expressions may also be used for the calculation of heat (^{0}C), $\grave{Y}$ in the reactors which in turn is a measure of the reactor's stability.
(iii) Also, the empirical formula derived can be used to determine the contribution of heat or temperature (^{0}C) to the stability of the reactor during operation or accident.
(iv) The estimated value of $\grave{Y}$ when X_j is zero is 139.3887 with a standard error of 29.8732.
(v) The slope represent the estimated change in heat ($\grave{Y}$) per unit change in fuel (X_j), is given as 110.9289 with a standard error of 4.1527.
(vi)The value of coefficient of determination (R^2) explains the proportion of the variation in heat that can be accounted for by variation in fuel as 0.9875.
(vii) The correlation between heat ($\grave{Y}$) and fuel (X_j) is 0.9938.
(viii) A significance test that the slope is zero resulted in a t-value of 26.7122. The significance level of this t-test is 0.0000. Since $0.0000 < 0.0500$, the hypothesis that the slope is zero is rejected.
(ix) The lower limit of the 95% confidence interval for the slope is 101.5348 and the upper limit is 120.3231. The estimated intercept is 139.3887.

In conclusion the research investigated the cooling problem of the nuclear reactor fuel, by conducting safety margin test on design decay heat and design volume of the fuel in the reactor core. Linear Regression Analysis Techniques was applied on some typical Water-Cooled Reactor Design (WCRD) models. The results of the statistical analysis on these types of nuclear reactor models reveals that the WCRD models promises stability under application of small size of uranium (fuel) at 9g and below than large size of uranium (fuel) at 12g and above. Meanwhile, at 9g of fuel element the reactor seems to be most stable and safer as the regression plot was optimized. The results of the statistical analysis on these types of nuclear reactor models reveals that the WCRD models promises stability under application of small size of uranium (fuel) at 9g and below than large size of uranium (fuel) at 12g and above. Meanwhile, at 9g of fuel element the reactor seems to be most stable and safer as the regression plot was optimized, that is the least squares method finds its optimum when the sum, *S*, of squared residuals

$$S = \sum_{i=1}^{n} r_i^2$$

is a minimum at the given mass (9g) of fuel element.

In this work the results shown that the mass of fuel in the operating reactor could contribute to the safety of the reactor. Also, the safety margin prediction of up to 0.62% has been validated for reactor design models on water-cooled reactor regarding the fuel temperature, the implication of research effort served as an advantage over the current 5.1% challenging problem for plant engineers to predict the safety margin limit. According to Xianxun Yuan (2007, P49) in “Stochastic Modeling of Deterioration in Nuclear Power Plants Components” a challenging problem of plant engineers is to predict the end of life of a system safety margin up to 5.1% validation.

However, the current design limits for various reactors Safety in a nuclear power plant, defined by the relative increase and decrease in the parametric range at a chosen operating point from its original value, varies from station to station.

Finally, the discoveries on fuel size effect on the power reactor stability and water-cooled reactor safety factor should provide a new method for reactor design concept taken cognizant of the fuel size effect and pressure built-up trouble in the reactor core. This shall also provide a good, novel approach and method for multi-objective decision-making based on six dissimilar objectives attributes**:** evolving technology, effectiveness, efficiency, cost, safety and failure. The implication of this research effort to Nigeria’s nuclear power project drive.
It is therefore recommended that for countries wishing to include nuclear energy for the generation of electricity, like Nigeria, the design input parameters of the selected nuclear reactor should undergo test and analysis using RAT for optimization and choice.

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