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Discovering Thoughts, Inventing Future

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By Nasrollah Hamidi, India Williams & Hushmand Hamidi

South Carolina State University

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Strictly as per the compliance and regulations of:

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I. Introduction

Earth contains 1,386 million cubic kilometers (Mckm) of water, composed of 35.5 Mckm (2.5 %) freshwater, where less than 0.75% of it is sustainably managed, and its resources are diminishing by the progress of civilization, causing water anxiety throughout the world. [1] The water stress would be alleviated far and wide, by harvesting the renewable, invisible atmospheric vapor (equivalent to 12,900 cubic kilometers of liquid water), by developing "atmospheric water generators" (AWGs). [2,3] In some arid and humid areas of Asia, America, and Africa, fog collectors and AWGs have been installed to alleviate local water stress and prevent forced immigration and poverty. [4–6]

Water calamity - resulting from climatic conditions, wars, urbanization, excess usage, natural and industrial pollution- is among the 5th global risk that impacts societies and the lives of almost 11% of Earth's population. [7–10] It is estimated that by 2050 nearly half of the world's population will be stressed for clean water, [8, 11] including 40 out of 50 USA States. Worldwide, potable water accelerated consumption continues to increase thrice within the last 50 years. [12,13] Food production withdraws over 74% of water, and; a 14% increase in food production and water withdrawal was predicted by 2030. [14–16] Desalination of seawater and inland saline water, [17–19] could alleviate water stress for more than 4 billion people [20] who live in salty regions.[21] Moreover, mineral contamination is a fundamental problem in many places, such as 50 countries living in the Pacific Ring of Fire. [22] The availability of individual AGW units working with the forces of nature would alleviate many water-stressed situations.

The amount of steam, the third most abundant gas in the Earth's atmosphere (~1-3%, depending on location), [23] is measured as the percent of relative humidity (% RH), and its concentration depends on the location, time, temperature, geographic and climatic conditions. [3, 24] A warmer atmosphere holds more moisture- about 7 percent more per 1°C of warming. These changes cause dewfall as a natural water source for plants and animals, particularly in arid and humid regions. Dew collections are also used for human consumption as AWGs become more popular. [25] Active AWGs require a significant heat release, and their mechanism is more thermodynamically complicated than passive AWGs and fog harvesters. [18, 26–29]

II. Progresses in the Field

The development of stimuli-responsive polymeric materials that exhibit controllable wettability in response to external stimuli has contributed to the success of atmospheric water generators (AWGs). For example, temperature-responsive polymers regulate

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water condensation and release at the molecular level by a phase transition from hydrophilic to hydrophobic, as a response to the changes in temperature. When these polymers are incorporated into an interpenetrating polymeric gel network, they can capture moisture from the air at lower temperatures and release water through a phase separation process at slightly higher temperatures. Stimuli-responsive polymers that have been used for this purpose include poly (acrylamide) [29], poly (N-vinyl caprolactone) [30], poly (N, N-diethylamino ethyl methacrylate), Poly (pyrrole chloride) (PPy-Cl)[31], poly(N-isopropyl acrylamide) (PNIPAM)[32] and some copolymers such as poly (L-lactic acid)−poly(ethylene glycol)−poly (L-lactic acid), [33] These materials exist in a hydrophilic state in which they absorb environmental water quickly, but they can be controllably switched to a hydrophobic state to release the water they contain without the need for energy-intensive processes. This behavior has led to the creation of responsive nanostructured polymer materials and systems, including thin films, particulates, and assemblies, that offer a new opportunity for AWG development. Intelligent materials, alone or combined with hygroscopic minerals and hygroscopic polymers, have provided an effective moisture absorption and desorption network. [34]

PNIPAM is one such stimuli-responsive polymer that undergoes a phase transition at its lower critical solution temperature (LCST), which is around 32 °C. [32] Hair-sized fibers made of a mixture of hydrophobic plastics and hydrophilic PNIPAM have been shown to capture water from a highly humid atmosphere at lower temperatures (below 25 °C) within a few minutes and release it at temperatures above 35 °C. [32] The amounts of thermoresponsive PNIPAM in the skin layer controlled the wettability of the fibers. Other hydrophilic polymers, such as nylon, have also been effective when electro-spared on the surface of the fibers. Similarly, a combination of PNIPAM with hydrophilic sodium alginate has been shown to create an interpenetrating polymer network gel that can capture moisture from the air and deliver liquid water directly. [5, 35–37]

Metal-organic frameworks (MOFs), which result from reticular chemistry, are another kind of three-dimensional interconnected network of highly porous crystalline solid materials suitable for AWGs fabrication. [23, 38, 39] The desorption process requires heat input depending on the water molecules' adsorption strength to reach regeneration temperature, ranging from 70 to 170°C. [18, 40]

Hygroscopic minerals, such as calcium chloride, lithium chloride, lithium bromide, silica gel, and zeolite, are also effective in attracting moisture everywhere, in very low and highly humid environments. [5, 41–45] These moisture absorbents have been used to fabricate AWGs that harvest moisture at night when the worm air gets cold and its humidity increases. The water desorption occurred during the day by heating the hygroscopic bed with solar radiation in a closed container. [5] In contrast to the conventional method of extracting water from dry, arid environments, this process requires less energy since, in the dry and arid regions experiencing a 20% RH at 30 °C, an energy-intensive and impractical process must cool the air to below its dew point (∼ < 4 °C) to turn vapor into liquid. However, by heating the humid descants in a closed container, air humidity reaches above 80% RH at 30 °C in the cabin, then the vapor liquefied at temperatures below the dew point (below 26 °C). This process requires less energy than extracting water from any dry and arid environments. [46, 47]

This study presents the preparation and process of absorption and desorption of a poly (acrylamide) hydrogel sample using TGA and DSC. The highest desorption rate temperature and its energy barrier were estimated. The effectiveness of the hydrogel in obtaining water from the environment and fabricating AWGs has been previously studied by other researchers.[29] The obtained values were consistent with expectations and supported the findings in the existing literature. This research occurred under natural environmental conditions, not a controlled environment and artificial simulations.

III. Experimental

a) Materials

Carbon nanotubes (CNTs), nitric acid, sulfuric acid, acrylamide (AA), N, N'-methylene bis acrylamide (MBAA), and benzyl peroxide were purchased from Fisher Scientific, a Thermo Fischer Scientific (USA) company. They were used as received. Fresh distilled water was prepared in the lab.

b) Synthesis

5 mL of distilled water, 1 g of acrylamide (AA), 0.85 mg of N, N'-methylene-bis- acrylamide (MBAA) as a crosslinker, 0.56 mg of benzyl peroxide as the polymerization initiator, and 220 mg of CNT as solar heat absorbent were added to a 60 mL ThermoScientific™ screwed cap septum vials. The mixture was held for 30 min under a stream of 30 mL.min-1 ultrapure argon to eliminate the oxygen present, then kept in an ultrasound bath for 2 hours. The mixture was incubated at 60 °C for a day to polymerize. The obtained hydrogel sample was freeze-dried for 24 hours; then it was immersed in a 1 M solution of CaCl2 for 24 hours under laboratory conditions. The saturated sample of hydrogel (DHG) was dried in an oven at 80 °C for a week. Water absorption of the DHG in the outside environment was not studied, and the desorption of water from the DHG by sunlight was also not explored.

c) Thermogravimetric Analysis (TGA)

The TGA studies were conducted on a TGA-7 Thermogravimetric Analyzer (PerkinElmer, Inc., USA) controlled by Pyrus 13.2.3 software on a Dell PC. The instrument was calibrated using a four-point calibration method since the thermocouple in this device is not in direct contact with the sample. The absorption reaction was prevented by increasing temperature linearly and a well-controlled nitrogen stream of 60 mLmin-1 (room temperature and atmospheric pressure), which carried the volatiles away as soon as they formed. The sample weight preserved was recorded continuously with the corresponding temperature and time. To accurately determine the kinetics parameters, several scans were carried out at different heating rates (β), including 0.5, 1, 2, and 5 Kmin-1. After each scan, the sample was exposed to the lab environment for a few days to saturate with vapor. The data were downloaded to Microsoft Excel for analysis. The values of the extent of desorption (α) for each sample were estimated by (100-%Wi)/100, where % Wi represents the normalized weight of the remaining sample. The values of α increase from zero to the extent that the dehydration occurred, instead of to one, as the dehydration progressed from initiation to completion, respectively.

d) Differential Scanning Calorimetry (DSC)

The DSC experiments were performed using a DSC-7 Differential Scanning Calorimeter (PerkinElmer, Inc., USA) under a stream of argon gas at a flow rate of 60 mLmin-1. The instrument was operated using Pyrus 13.2.3 on a Dell PC. The instrument was calibrated using a standard sample of indium. A well-dried DHG aliquot was crashed and blended in a mortar and pestle before inserting it into an aluminum DSC pan for thermal analysis.

IV. Results and Discussions

a) Water Sorption Experiments

The environmental vapor sorption test was conducted on a Mettler-Toledo Balance at the laboratory conditions of 28 °C, 57% RH during July 2022, in Hodge Hall Lab 314. About 1 g of the previously generated DHG was placed on the scale to monitor its water absorption capacity through weight measurement over three days, as shown in Fig. 1. As time progressed, the weight of the DHG increased, indicating that water was being absorbed into the hydrogel from the environment. The DHG absorbed water over 20% of its weight water in, during 7.5 hours (hs), 50% of its weight after 28hs, and over 60% of its original weight when exposed to the lab environment for 50 hours. The rate of moisture absorption by the hydrogel decreased over time. The initial moisture absorption rate was 0.042%/h; it became slower on the second day (0.022%/h), and much slower on the third day (0.012 %/min) of the environmental exposure.

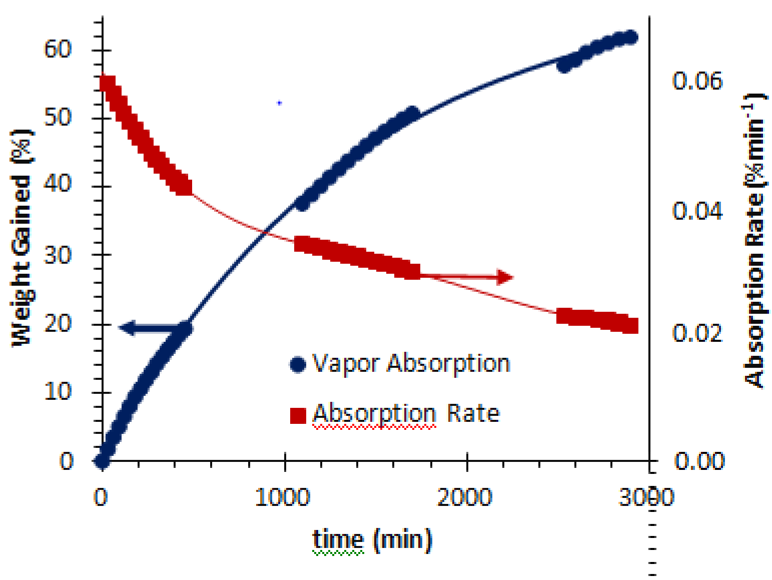

Fig. 1: Variation of the Hydrogel Weight and the Water Absorption Rate.

b) Photo-Thermal Bath

Charcoal was taken as an example of photothermal absorbent material assuming that its photo absorption is similar to as that of the CNTs. The temperature increase of the charcoal was monitored every 5 mins interval, using an infrared thermometer, from 10 AM to 1 PM on a sunny day (June 2022) when the highest daily temperature was 36 °C. Initially, the charcoal absorbed solar heat at a very high rate; however, after 50 min, the temperature changes plateaued, as shown by the graph in Fig. 2.

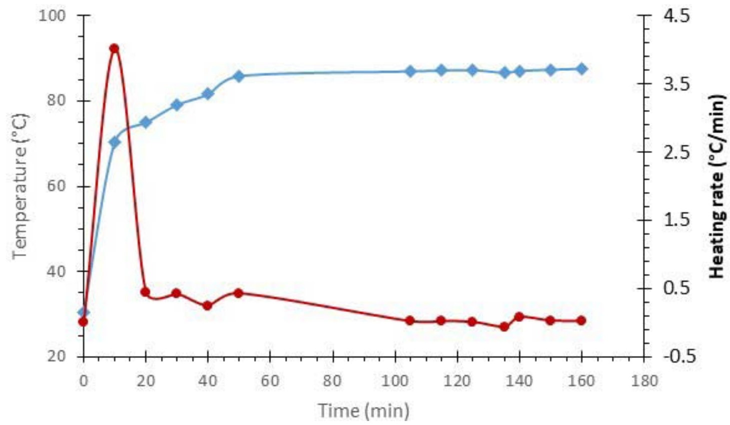

Fig. 2: A Graphical Representation of the Change in Charcoal Temperatures under Direct Sunlight in an Aluminum Box.

c) *Differential Scanning Calorimetry (DSC)*

The physical properties such as melting point (mp) and glass transition temperature (Tg) are significant properties of solid materials since they determine their industrial application and the types of processing. Polyacrylamide (PAA) has a relatively high melting point (>300 °C) and glass transition temperature (~163 °C) due to strong polar interactions between its amide groups. During the first DSC scan of the DHG (Fig. 3) physical changes at temperatures ~ 50. °C (ΔH ~ 22.7 Jg-1), and 179 °C (ΔH ~ 371 Jg-1) were observed. These transitions are not related to PAA's melting point or glass transition temperature, nor are they related to the melting point of acrylamide (84.5 °C). We can, therefore, conclude that they are related to the new product, DHG, as expected.

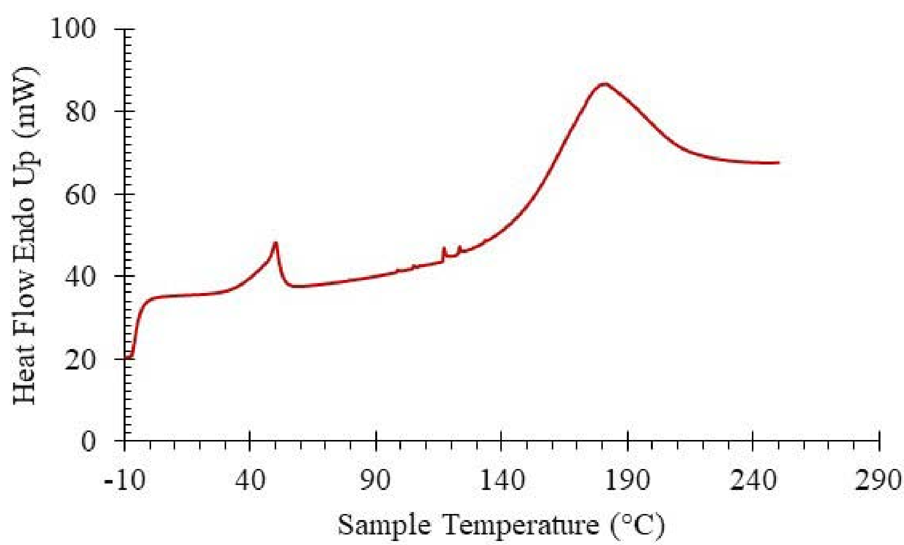

Fig. 3: Thermogram of Differential Scanning Calorimetry (DSC) of a Sample (27.73 mg) of DHG at the $\beta = 10\ Kmin^{-1}$

The transition that initiated around 35 °C and maximized around 50 °C could be related to a phase transition and conformational rearrangements of PAA gel. This thermal transition could also be responsible for the spontaneous release of absorbed vapor in the form of liquid water at temperatures above 50°C as observed by TGA measurements documented in the next sections.

d) *Thermogravimetry Studies*

A TGA pan was loaded with 32 mg of dry hydrogel for water desorption analysis. The sample was left at room condition for three days to absorb humidity, and then subjected to TGA testing. The water desorption was initiated as soon as the sample was placed into the TGA pan (27-30 °C), as shown by the TGA thermograms in Fig. 4. The 3rd and 4th scans were made after the sample was regenerated for a few days in the lab. The

DHG released about 24% of the absorbed water during the first scan. The second scan was taken a few hours after the first scan when the sample had lost most of its absorbed water and did not have enough time to regenerate.

The upper section of Fig. 4 shows the water desorption thermograms and the lower section shows the dehydration rates. In all scans, the water desorption was initiated slowly; its rate increased progressively as temperature increased, and reached maximum around 79 °C, a temperature below the boiling point of water (100 °C). Our results are consistent with previous studies, which have also reported the release of water from DHG below the water's boiling point. [29]

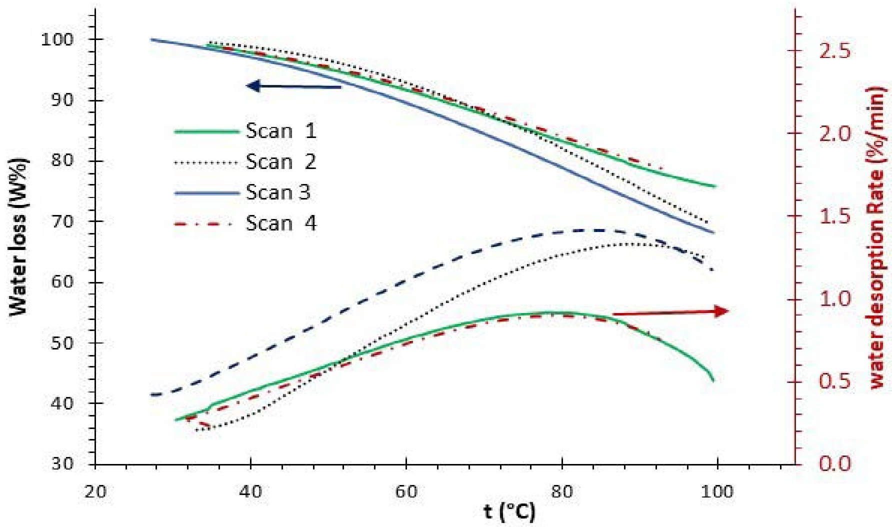

Fig. 4: (Top) Thermograms of Water Desorption and (Bottom) the Water Desorption Rate of the DHG from Room Temperature to 100 °C.

e) Kinetics of Water Desorption

The kinetics of the thermally simulated dehydration of the deliquescent hydrogel (DHG) was studied by the measurement and parameterization of the rates of weight loss originating by eq.1: [48]

$$DHG(\ active\ ) \xrightarrow{\Delta} DHG + H\ \ 2O\ (vapor) \quad (1)$$

Moist DHG (active) was heated ($\xrightarrow{\Delta}$) to release the absorbed humidity in the form of vapor [H2O (vapor)] or nano-droplets of water that were carried away with a 60 mLmin-1 stream of nitrogen. The rate of thermally stimulated dehydration of DHG (-dW/dt) is expressed by the negative derivative of the TGA thermogram data (-DTGA) of dehydration initiated by the changes in temperature. The rate of dehydration is parameterized by the advancement of dehydration (α) where (1-α) represents the residual amount of DHG(active), the mechanism of reaction expressed by f (α) function (Table 1) and the Arrhenius rate constant [k(T)], as shown by Eq. 2: [49–55].

$$Rate = \frac{d(1-\alpha)}{dt} = -k(T).f(\alpha) \quad (2)$$

Where T represents the absolute temperature value in K, Ea represents the energy barer to release water by the DHG, and R = 8.314 J mol-1 K-1 is the universal gas constant. Equation (2) is the starting point for various differential kinetic methods and applies to any reaction type.

The values of E_a, and lnA, with the pre-assumed form of f (α), are estimated from the slope and intercept of the Arrhenius plot based on eq. 3, (ln [Rate/f(α)] = ln k versus 1/T) as shown in Figs. 5, for each given α values, respectively.

$$ln\left[-\frac{dw/dt}{f(\alpha)}\right] = l\,n\left|\frac{\frac{d\alpha}{dt}}{f(\alpha)}\right| = ln\ k = -\frac{\boldsymbol{E_a}}{\boldsymbol{RT}} + ln\,\boldsymbol{A} \quad (3)$$

The TGA data were analyzed using Eq. 3, which provides information on the weight, temperature, and rate of weight loss at each interval. The isoconversional method, which assumes that the mechanism of a reaction remains the same at a given α value regardless of the heating rate, was used to construct the Arrhenius plot for a given α value. This work using the pre-assumed models expressed by f (α) functions (see Table 1 for details). The Arrhenius plots for the dehydration of the DHG according to each f (α) are shown in Fig. 5, with the x-axis representing the reciprocal of temperature (in Kelvin) and the y-axis representing the natural logarithm of the ratio of the dehydration rate and a given f (α) function. The slope of the adjusted line to the data represents the value of the activation energy divided by the gas constant (Ea/R). As expected, a negative slope of the adjusted line to the experimental data indicates an endothermic activation energy barrier. The pre-assumed models, f (α) values used in this work are shown in Table 1. If the data shows a positive slope, this indicates that there is no energy barrier for dehydration; and that the reaction is self-activated and spontaneous. This phenomenon was observed for some of the extent of reactions as shown in lines of Fig 4.

Table 1: Set of *f* (α) Functions that were used as Reaction Models to Describe the Thermally Stimulated Water Release of the Deliquescent Hygroscopic Hydrogel System (DHG).

No.	Reaction Model	Code	$f(\alpha)$
1	Power law	P4	$4\alpha^{3/4}$
2	Power law	P3	$3\alpha^{2/3}$
3	Power law	P2	$2\alpha^{1/2}$
4	Power law	P2/3	$2/3\alpha^{-1/2}$
5	One-dimensional diffusion	D1	$1/2\alpha^{-1}$
6	Mampel (first order)	F1	$(1-\alpha)$
7	Avrami–Erofeev	A4	$4(1-\alpha)[-\ln(1-\alpha)]^{3/4}$
8	Avrami–Erofeev	A3	$3(1-\alpha)[-\ln(1-\alpha)]^{2/3}$
9	Avrami–Erofeev	A2	$2(1-\alpha)[-\ln(1-\alpha)]^{1/2}$
10	Three-dimensional diffusion	D3	$3/2(1-\alpha)^{2/3}[1-(1-\alpha)^{1/3}]^{-1}$
11	Contracting sphere	R3	$3(1-\alpha)^{2/3}$
12	Contracting cylinder	R2	$2(1-\alpha)^{1/2}$
13	Two-dimensional diffusion	D2	$[-\ln(1-\alpha)]^{-1}$
14	Random Scission	L2	$2(\alpha^{1/2}-\alpha)$

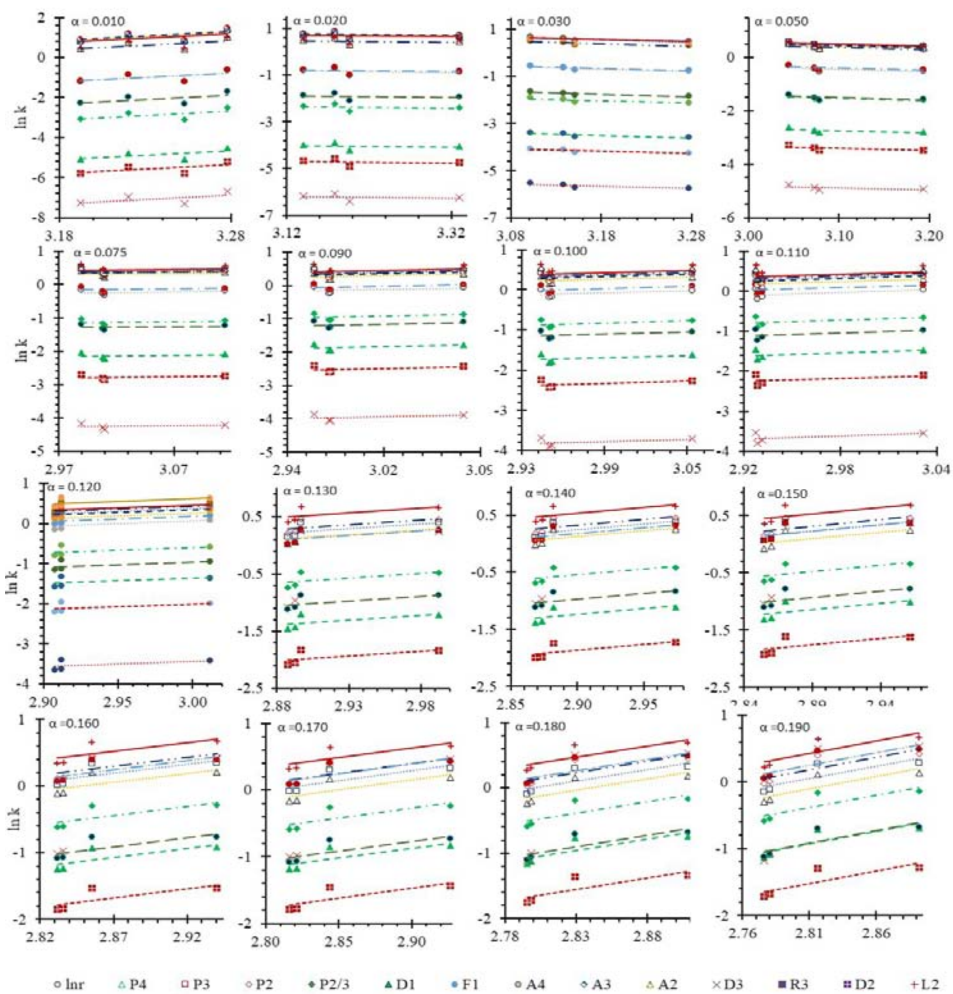

Fig. 5: Arrhenius Plots of the Deliquescent Hygroscopic Hydrogel (DHG) Dehydration at the Given α values.

Fig. 5 represents the Arrhenius plots, according to the isoconversional method, for each indicated α value. The energy barrier for each extent of reaction was obtained for the slope of the corresponding plot are shown in Fig. 6.

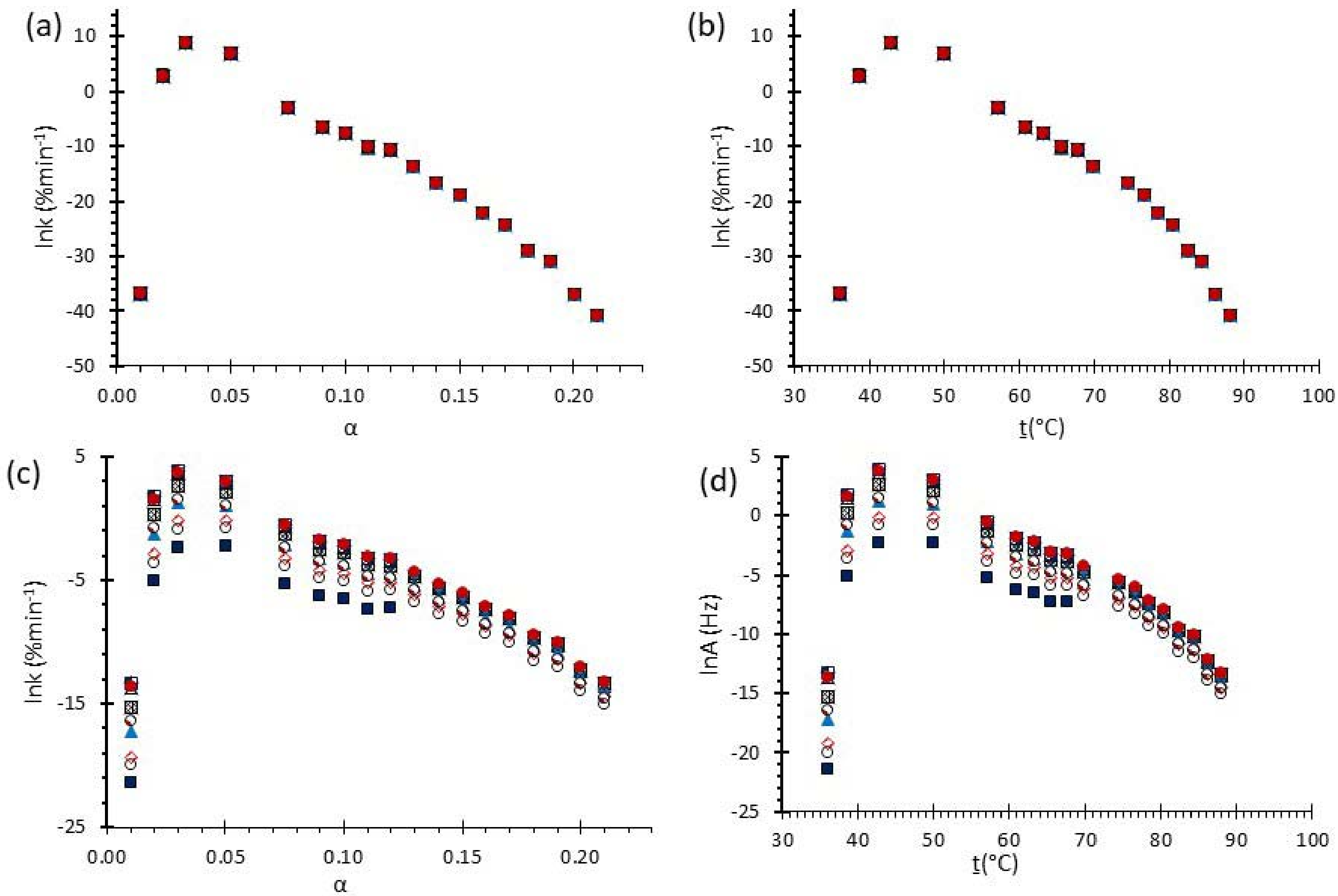

Fig. 6: Variation of (a) Activation Energy Barrier of Dehydration (Ea) and (c) Values of Arrhenius Pre-Exponential Factor (lnA) of DHG Versus the Corresponding Extent of Reaction (α), Respectively; and (b) Ea and (d) lnA of DHG Versus the Corresponding Average Temperatures (t), Respectively.

Figure 6 (a) represents the energy barrier values obtained by applying the isoconversional method for each α value (Ea, α) using the reaction models enlisted in Table 1, where the values of α ranged from 0.010 to 0.210. The corresponding lnA values are shown in Fig. 6(c); the corresponding r2 values are shown in Fig. 7. For a given value of α, the estimated values of Ea, α obtained from the slopes of the adjusted lines were found to be closed to each other, independent of the f(α) function, as expected. For instance, the average values of the Ea, α obtained from the slopes of all models for α = 0.075 was Ea, 0.075 = -2.88 ±0.01 kJmol-1 with the corresponding lnAα = 1.70 ± 1.48 and for α = 0.120, the Ea, 0.120 = -10.70 ±0.01 kJmol-1, with the corresponding lnAα = -4.22 ± 1.19. However, the variations of the values of lnAα depended on the f(α) function, as expected.

The nature of the isoconversional method leads to the fact that at a given α value each thermogram possesses its own reaction rate and temperature; therefore, there is not a given temperature value for a given α value. To evaluate the variations of kinetics parameters by temperature, the approach was to take the average temperature value (t) for each α. The variation of Ea, α and lnAα values with corresponding average temperatures are shown in Fig. 6 (b) and (d), respectively. A comparison of Figs. 6 (a) and (b) shows that the values of Ea, α have similar trends indicating the average temperature approach is acceptable. Similar trends were observed for the variations of lnAa versus α and t as shown by Figs 6 (b) and (d). Moreover, variations of both Ea, α and lnAα versus α and t have shown a similar trend, indicating their interdependence behavior, as was expected. These values, most likely, are composite values, determined by the sum of activation energy barriers of the involved individual steps by assuming that the water delivery has the Arrhenius temperature dependency. [50, 56, 57] These values are called "effective," "apparent," "empirical," or "global," and they are different from intrinsic parameters. The effective activation energy can vary strongly with the temperature and the extent of conversion [58–60] or take on negative values. [61] Such discrepancies are not expected for the E_a values of a single-step chemical reaction or a physical change. As the reaction progressed, the Ea, α of DHG followed its paths according to the nature of the reaction models and reactants, as shown by the graphs in Fig. 6 (a & c).

The approach to evaluating independently Aα and f (α) in a model-free method was explained in detail by other authors. [62–64] These studies emphasized correlations between the reaction rate, activation energy, pre-exponential factors, and changes in the rate-limiting steps of the individual steps of a chemical reaction. Since the rate of reaction (Rα) at a given α value is expressed as the product of two terms, [Aα f (α)] and [exp (−Eα/RT)], therefore, as the value of Rα decreases and one of the two terms increases the other decreases. When the term, Eα, becomes dominant, it is a sign of a change in the limiting step of the reaction.

The values of Ea of the DHG sample increased with increasing temperature. They reached a maximum value of ~45 °C as indicated in Fig. 6(b). They continuously descended till the end of the dehydration process, as shown in Fig. 6. The highest energy barrier of dehydration of DHG was at the temperature range of 39-50 °C. This behavior is expected since the DHG spontaneously absorbs moisture from the environment at temperatures below 40 °C and releases it at temperatures above 40 °C. The sample weight loss started as soon as it was placed in the TGA pan, where the easy-access water was removed by the high nitrogen flow (60 mL. min-1) passing into the system. The increase of Ea in the plot by increased temperatures is due to reducing the amounts of easy-to-arrest surface water. The highest value of Ea required to release water was around 10 kJmol-1 at 45 °C; which is a very low amount of energy and easily achievable. At temperatures above 50 °C, the amounts of Ea were decreased by increasing the temperature, indicating that the DHG easier release water at moderately low temperatures (t > 50°C), which is achievable by sunlight as shown in Fig. 2. The moisture release is due to the phase transition of the polymer gel which causes the released of stored water spontaneously. The conformational transition of the DHG was also confirmed by DSC measurements as shown in Fig. 3

Figure 7 shows the values of r2 when the experimental data were fit into a given α value for a corresponding f(α) models listed in Table 1. The dehydration process at the extent of reaction larger than 0.12, and hence higher temperatures (t > 70 °C), can be fitted into all models except A2, A3, A4, and D3. Not always, the real reaction mechanism could be judge by the best-fitted model to the experimental data.

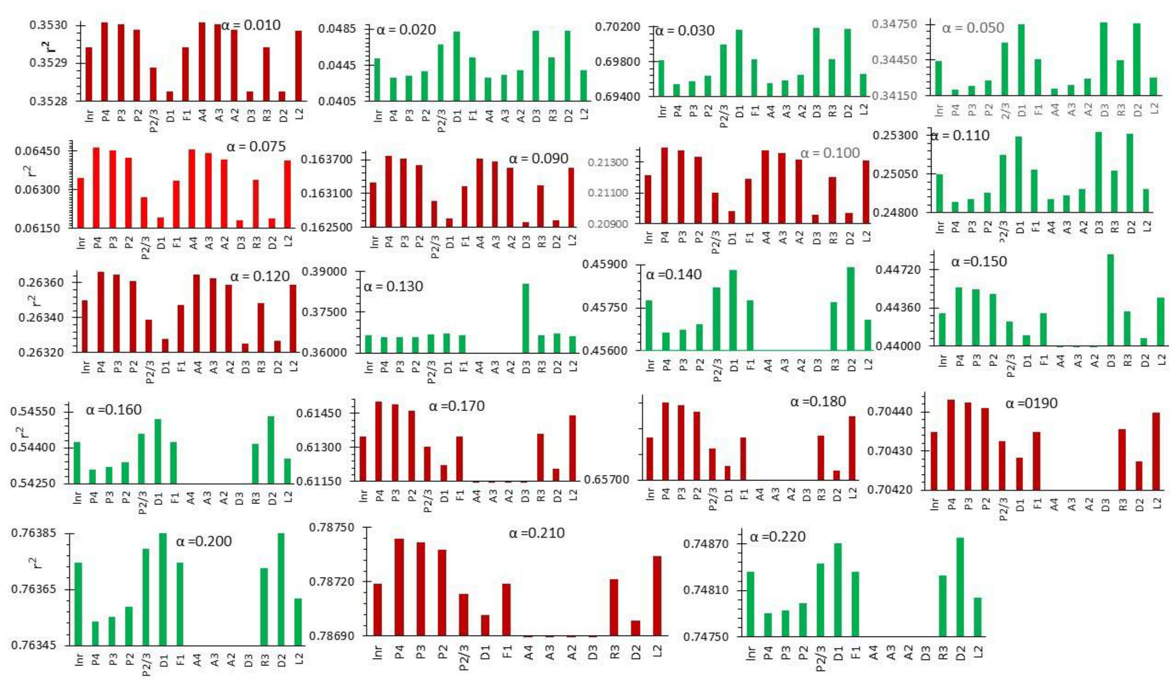

Fig. 7: Variations of the Values of r2 According to f (α) Models Enlisted in Table1.

V. Summary, Conclusions, and Remarks

Polyamide gel that hosts the hygroscopic calcium chloride was made of acrylamide combined with N, N'-methylenebisacrylamide in the presence of carbon nanotubes (DHG). DHG absorbs moisture from the environment at lower temperatures and desorbs water at a slightly higher temperature (t > 40 °C). Here, the relationship between thermosensitive and water desorption of the DHG was reported.

The crosslinked hydrogel network maintains the deliquescent solution in a solid form. Thus its water harvesting capacity is enhanced.

In this study, 14 most used reaction models, tabulated in Table 1, were analyzed, and all provided very similar results. The estimated amount of Ea was independent of the model, with a standard deviation of less than 0.07 kJmol-1. Therefore, the data from all models fall on top of each other in the corresponding graphs as shown in Fig 5 (a).

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Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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The Elephant in the Room; Preaching or Working on Climate Change

By Miguel Schloss

Abstract- To lead people walk behind them(Lao Tzu)

A lot has been debated about the effects of carbon emissions and their impact on climate change. Of all issues that need to be addressed, the one that stands out refers to the power sector, which absorbs more primary energy than any other sector, and accounts for anywhere between a third and half of carbon emissions worldwide.

At stake is the need to assure continued economic development, and ensuring the associated improvements in standards of living, while doing so with declining carbon emissions. Over the decades, growth has been propelled by massive expansion of energy demand, powered by hydrocarbons that brought about increases in CO2 emissions. Achieving both growth and decarbonizing economies will be one of the most challenging developments over the coming decades.

Keywords: climate change conference of the parties (COP); carbon dioxide (CO2) and Green House Gas (GHC) emissions; fossil fuels; renewables; organization for economic cooperation and development (OECD); emerging economies; energy efficiency, security and coverage; carbon pricing and taxing externalities; renewables; load factors and reserve capacity; transition and adaptation arrangements; economic adjustment; enabling policy environment.

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THEELEPHANTINTHEROOMPREACHINGORWORKINGONCLIMATECHANGE

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The Elephant in the Room; Preaching or Working on Climate Change

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A lot has been debated about the effects of carbon emissions and their impact on climate change. Of all issues that need to be addressed, the one that stands out refers to the power sector, which absorbs more primary energy than any other sector, and accounts for anywhere between a third and half of carbon emissions worldwide.

At stake is the need to assure continued economic development, and ensuring the associated improvements in standards of living, while doing so with declining carbon emissions. Over the decades, growth has been propelled by massive expansion of energy demand, powered by hydrocarbons that brought about increases in CO2 emissions. Achieving both growth and decarbonizing economies will be one of the most challenging developments over the coming decades.

In recent years, a growing consensus has emerged on the need to reverse growth of emissions to prevent global atmospheric conditions from generating further temperature increases. To this end, 195 countries entered into an international agreement in Paris to limit temperature increase 1.5 degrees Centigrade of pre-industrial levels by mid-century [1]– but there is still a long way to go to cap global warming at this level, and thus no basis for complacence.

Actually, progress towards this aim remained negligible over the last 20 years, with marginal changes in CO2 emissions. This paper does not address the full range of issues, such as what to do on research and development of new technologies, how to focus on hard-to-abate sectors like mining, shipping, etc. Instead, it focuses on how to respond to this lack of progress, while assuring further economic progress for much of the developing world.

There are a wide range of ways that are being advocated, from the institution of stronger environmental regulations and associated monitoring to force enterprises to set up plans and investments aimed at reducing emissions (in one end of the debate), all the way to enhancing enabling conditions for environmental investment through pricing and taxation policies to facilitate financial and human resource mobilization to deal with the issue (in the other end of the arguments) – or top-down vs. bottom-up approaches so to speak.

This paper doesn't take a stand of one approach or another, as in the end, much depends on institutional capabilities, availability of resources, and a good diagnosis of the issues that each country needs to address. The record so far, however, points towards better and worse ways to proceed, and that a more effective way to proceed depends on a good understanding of both the problems to be addressed and the constraints to do so. This paper is an attempt to shed light on these issues, and help to choose a more effective path to address the issue.

Keywords: climate change conference of the parties (COP); carbon dioxide (CO2) and Green House Gas (GHC) emissions; fossil fuels; renewables; organization for economic cooperation and development (OECD); emerging economies; energy efficiency, security and coverage; carbon pricing and taxing externalities; renewables; load factors and reserve capacity; transition and adaptation arrangements; economic adjustment; enabling policy environment.

I. Introduction

WHERE ARE WE AT PRESENT?--*What has he done to wear so many scars?*

Does he change the course of rivers? Does he pollute the moon and stars?(Bob Dylan)

To put matters crudely, despite calls to advance the green transition and strong growth in renewables, fossil fuels remain dominant, contributing to 82% of our total energy consumption.

Global energy demand rose by 1.1% to 604 exajoules, a new record in 2022. While the growth rate has slowed modestly, this might have been due to specific factors. Still, global energy consumption has doubled since 1985.

Oil and renewables saw the largest increase in demand in terms of units of energy (exajoules), while natural gas and nuclear energy consumption fell in 2022. Fossil fuels' share of global primary energy demand fell slightly from 82.3% to 81.8%, while renewables' share rose from 6.7% to 7.5%.

The path to decarbonizing the world remains a long one. With global energy demand expected to rise sharply in the years ahead, to enable emerging nations to develop, we should see significant investments across all energy sources. In all, this should enable attractive, multi-decade investment opportunities.

Meanwhile, calls to advance the green transition supported the growth in renewables, which rose 13% in 2022, slightly above the annual growth rate of 12.6% over the last 10 years. As a result, the share of renewables in primary global energy consumption rose from 6.7% to a new record high of 7.5%. Renewables will continue to expand at a strong pace over the coming years, though from a relatively low base

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compared with traditional sources.Accordingly, fossil fuels remain king for a while and make up the lion's share of our thirst for energy, accounting for nearly 82% of the global demand.

As a result of higher absolute consumption of fossil fuels last year (up by 2.3 exajoules), energy-related carbon dioxide emissions (from industrial processes, flaring, and methane) rose 0.8% to a new record of 34.4 gigatons of CO2 equivalent in 2022. Emissions rose the most in Indonesia, India, the US,

Clearly, the progress in renewables is not making a dent in CO2 emissions, and a growing consensus is slowly emerging that the decarbonation race is not just about expanding renewables, but embracing risk and resilience consideration in climate change policy formulations , embracing proper feedback loops from civil society to ensure that there is a proper response to market demands , and building the necessary governance arrangements that are crucial in any "structural" changes to ensure that all interests are properly represented and responded to, and generate genuine sustainable solutions for all.

HOW DID WE GET HERE?–History does not repeat itself, but it rhymes (Attributed to Mark Twain)

Every so often, throughout history, humanity touches the seeming limits of development, leading to crises that forces us to rethink and change the way further growth and wellbeing can be achieved. This happened with population growth, with the attendant preoccupation on how limited agricultural output could accommodate the growing demand for food, and associatedclaims on limited agricultural land. The agricultural revolution and the ensuing productivity increase capable to surpass population growth, in the endenabled further enhancement of wellbeing for a growing population.

This seems to be happening at present again, when growing economic activity appears to be hitting the limits that nature is able to accommodate. As enhanced economic activity has hitherto been underpinned by growing energy use to replace human and animal toil for small engines, the carbon emissions of such equipmentisaccumulating in the atmosphere to the point that it is producing global warming threatening human existence in the longer term.

The Paris Agreement on climate change aims at precisely limiting global warming to no more than 1.5°C of pre-industrial levels by building a decarbonized economy by mid-century.

Such goal implies investments of at least US$16.5 trillion, and a profound transformation in production and transportation practices, investments in renewable energy, and other actions never seen to date.

Of course, no political, social or moral achievement of this magnitude or complexity is without formidable obstacles. There are vested interests to be confronted, attitudes to be changed, resistances to overcome. The problems are immediate, the ultimate goal frustratingly far away. So, the issue hinges on how to reconcile these seemingly conflicting strands.

The crisis triggered in Europe by the suspension of Russian gas supply, together with decisions to curb production of hydrocarbons, illustrate such conflict and, more importantly, the disconnect of the actions taken with geopolitical realities. These have triggered price increases to record levels, and a gap between the goals and achievements of the Paris agreements. A transition towards the agreed objectives will demand a decidedly more strategic and coherent approach. Just to mention a couple of real-life constraints, this will require special attention to:

- Coal-dependent economies, such as India and South Africa – which generate more than 70 and 85% of their electricity, respectively, from low-cost coal, with serious social and economic repercussions that will need more nuanced approaches to transition than those applied to date;
- Countries with important power generation facilities that are in energy-intensive and harder-to-abate sectors, which are difficult to decarbonize, such as mining and extractive industries, which constitute the mainstay of a good number of emerging economies.
- Any effort of this nature will require important human and financial resources to make progress within the absorption capacity of each country. Forcing ambitious and distant goals, or discouraging certain technologies with arbitrary regulations will not generate progress, and may even generate civil resistance and associated instabilities. [2]

THE PEBBLES ON THE ROAD--*Success is stumbling from failure to failure with no loss of enthusiasm*(Winston Churchill)

The energy sector, and society more generally, face significant challenges as we navigate the transition to a low carbon energy system. That will require understanding and judgement, bothof which will have to rely on empirical data and analyses that are usually presented to justify political postures to depict advancement in the global debate on the issue.

In fact, if one takes the goals and pledges agreed at the proceedings of Conference of the Parties (COP) meetings of the UN Climate Change Conference, one could easily conclude that all what is needed is to live up to the commitments to achieve the goals of a low carbonized economy. That said, the projections have an inevitable promotional aim to meet the political imperatives agreed at original Paris agreements, and are perilously dependent on underlying assumptions. Chief among them iseconomic growth (and associated energy demand), availability of financial resources, future technological development, which may not

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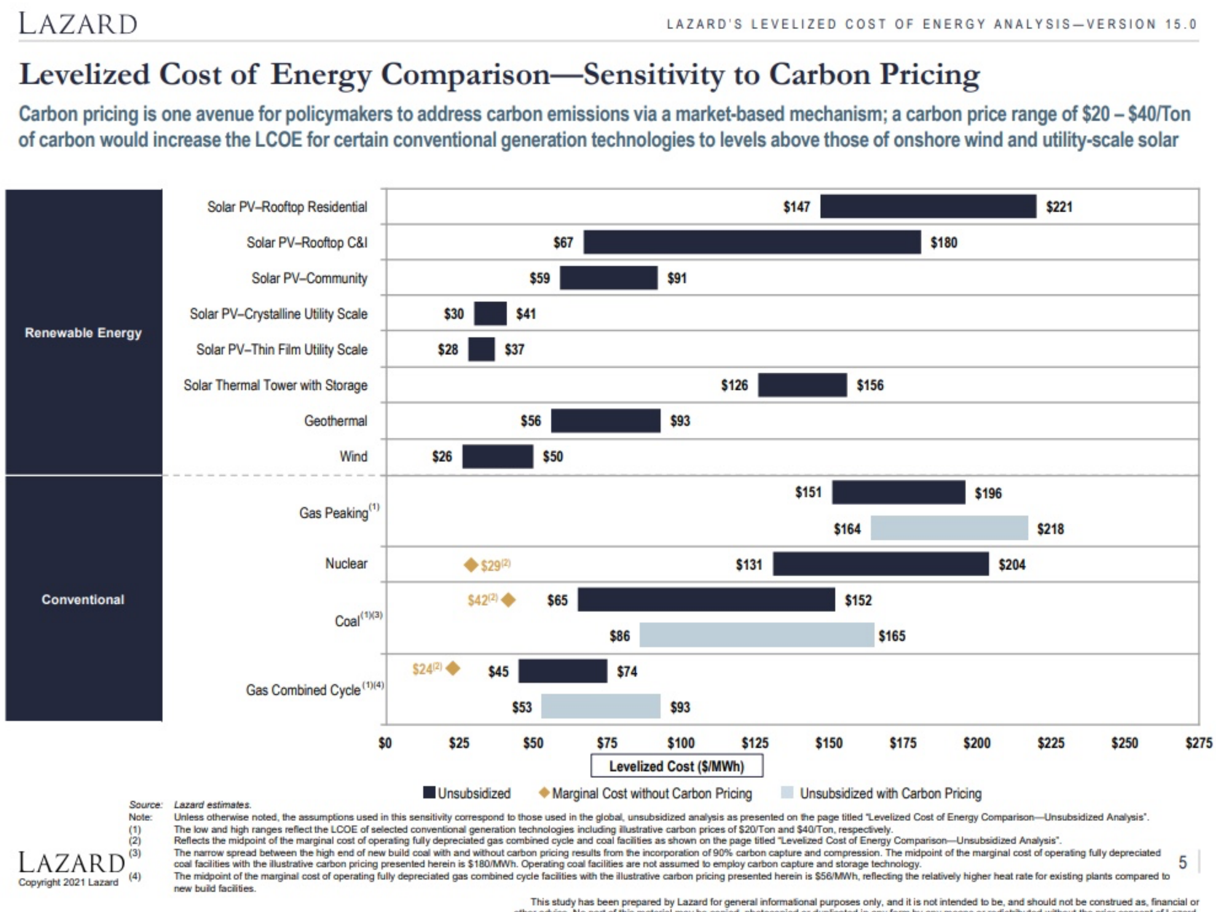
necessarily take place – at least at the pace assumed in the documentation underpinning COP meetings. In this connection:

First; a serious focus is needed on such assumptions, whichhave yet to be supported by detailed plans or executed to move them from studiesand proposals to execution, specifically concerning economic and affordability aspects, their organizational and governance implications, as well as the energy coverage that will be provided. Nor will execution be trivial, as it would require careful balancing of shorter-and longer-term risks thatcan make all the difference between viability, sustainability and ultimately the support that such programs among energy consumers –- be itcivil society or enterprise sector.

Second; renewable technologies are heavily location-specific and weather-dependent, and thus tend to have lower load factors than traditional sources, thereby requiring a proper energy base to provide backup from regular resources, such as gas fired generating facilities to provide low cost relatively limited CO2 emitting facilities. For the time being, and until the intermittent energy supply can be overcome due to weather related conditions of most renewables, power sector grid integration will be required through transmission investments over longer distances to link areas with adequate wind regimes or solar radiation, with household consumers and industrial areas.

Third; while, there is no question that the economic viability of renewables has improved over time, and its costs are currently broadly "in the ballpark" of traditional sources, if adjusted or levelized for carbon emissions, as can be seen in thetable below:



Fourth; consider able work will be necessary to make renewable sources more reliable, such as energy storage (which is overly expensive for the time being), geothermal options, requiring proper risk intermediation vehicles to bridge the mining/ geological with the power generation risks, the up scaling of run-of-river facilities, etc. to properly complement the capacities of existing and foreseen renewable facilities. In all, though, this situation will require for the time being traditional energy generating facilities for back-up and/or supplement the energy base of each country.

Adding such investments to overcome the constraints of current renewable sources, there should be no mistake: all indications are that low-cost energy and associated implications on economic growth, appear to be a thing of the past. Accordingly, if this is the direction that energy sources are likely to emerge, a future decarbonized era will require an increasingly efficient use of more expensive energy sources, if further economic development is to be secured.

Beyond the possibility of any slippage decarbonization plans, the International Panel on Climate Change (IPCC) reports makes clear that all pathways that limit warming to 1.5°C may inevitably depend on some carbon removal. Accordingly, beyond deep emission reductions, taking carbon out of the air will be necessary.This will require natural solutions (such as forestation) as well as nascent technologies that pull carbon dioxide directly from the air, as is being experimented in several countries.

WHAT WILL IT COST, AND WHO WILL PAY?-*People reach their pocketbooks without much grace*(popular saying)

Of all issues, revamping of the energy matrix to replace its reliance on fossil fuels for renewables is perhaps the biggest challenge to meet the Paris goals. Above all, the orders of magnitude are such that the matter will be inherently controversial, as competing claims on funds will require discerning attention on priorities, economies, organizational requirements with far-reaching consequences for society. To put matters in perspective, two points merit special attention:

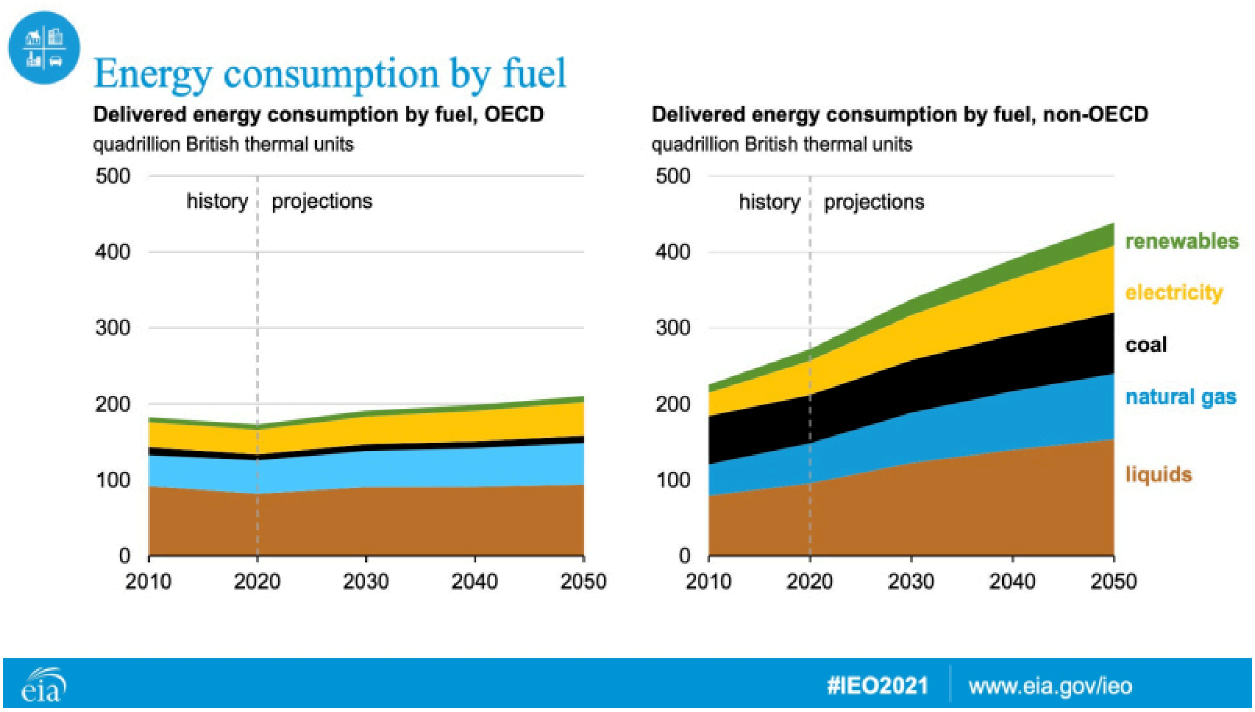
1. *Public Resources*. Capital spending on physical assets for energy and land-use systems in the net-zero transition to 2050 may amount about $275 trillion, or some $9.2 trillion per year on average, an annual increase, or as much as $3.5 trillion from today — compared with World Bank(WB) commitments hovering in the $2.4 to 2.7 billion a year range in the 2000's. This in itself highlights the increasing effort that will be needed in resource mobilization, price increases, and other such actions, as fiscal budgets are already overstretched in current and foreseen economic conditions. On this scale alone, the WB and multilaterals are puny. Allowing them to grow to fill the gap, without considering their effectiveness, may well be an unbridgeable stretch. So, the role that the WB and similar institutions, must be in the main catalytic (and inevitably marginal in terms of financial resources).Accordingly, greater focus will be required on pricing, taxation arrangements, and generation of incentives for such investments. This is a dramatic change from what the WB and other multilaterals have been doing, which in turn makes one wonder whether they are fit in their current form for the proposed job.
2. *Private Sector and Civil Society.* Governments and official institutions are struggling to deal with the issue, and if such trends continue, the agreed goals will not be met. A profound transformation in production and transportation practices, investments in renewable energy, fundamental recasting in the production of raw materials upstream and pricing policies are needed if decarbonization efforts are to succeed. As in other transformational efforts in the past, climate change will have to be solved by innovation and entrepreneurship, more than by multilaterals, governments and politicians. As throughout history, private enterprise cognizant of societal demands, and innovation will be required for transformational approaches. Any approach to the issue will ultimately have to rely more heavily on them. Official institutions may have to recast their approaches from a rhetorical and normative to a more open and enabling focus to problem-solving.

Accordingly, actions must be grounded on five points for a realistic chance of success:

1. At present, more than 70 countries, accounting for more than 80 percent of global CO2 emissions and about 90 percent of global GDP have put net-zero commitments in place, as have more than 5,000 companies, as part of the United Nations' Race to Zero campaign. Yet even if all the existing commitments and national climate pledges were fulfilled, estimates suggest that warming would exceed the agreed 1.5°C above preindustrial levels. Moreover, most of these commitments have yet to be supported by detailed plans of action. Nor will execution be trivial, as it would require careful balancing of shorter- and longer-term risks. Today, while the imperative to reach net-zero is increasingly recognized, the issue is not solved. This should not be surprising, given the scale of the task at hand. Achieving net-zero emissions by 2050 would entail fundamental transformation of the global economy.
2. The estimated capital spending on physical assets for energy and land-use systems mentioned above highlight the increasing resource mobilization efforts that will be needed, and ultimately the changed role that multilateral development banks must play in catalyzing the resource requirements over and above what official institutions can do to deal with the issue, including focus on pricing, taxation arrangements to mobilize resources and generate incentives for such investments.
3. The macro projections prepared hitherto inevitably imply a significantly up scaled financial effort among many players to properly anchor investment plans. However, taking these projections as top-down targets would be akin to "throwing money at the problem". The issue cannot be reduced to investing in a changed energy matrix to reduce carbon emissions. This is unlikely to occur, given the varying institutional capacities and other constraints in the countries concerned. Instead, an

effort will be required to involve stakeholders, bottom up, to identify the market demands to properly respond to them, including issues of affordability, energy security and coverage to avoid costly energy crises, and distorting subsidies of the past.

4. To build up such frameworks, major banks and other international financial bodies may have to establish common practices and frameworks (in a manner akin to the preparation of the Equator Principles), perhaps sponsored by the World Bank to exchange experiences, streamline existing practices to evaluate investments involving climate implicateons, risk sharing and/or other arrangements to facilitate entrance of new players and resources to upscale the investment effort.
5. The focus will have to concentrate in the main on emerging economies, where the bulk of economic growth, energy demand andCO_2 emission growth is likely to take place, and thus the overall effectiveness of the effort. While OECD countries have essentially kept current levels for the past 10-15 years, non-OECD economies have increased some 40% from similar levels at the beginning in the early 2000's — and if past trends continue, as is likely, non-OECD consumption levels will more than double those of developed countries by mid-century— as seen below:



Accordingly, energy transition and carbon emissions will hang largely on what will happen in emerging economies (particularly Asia), which merits focused attention and response to achieve significant decarbonization goals while meeting developing needs of those economies, where resource and funding mobilization constraints are the greatest. [3]

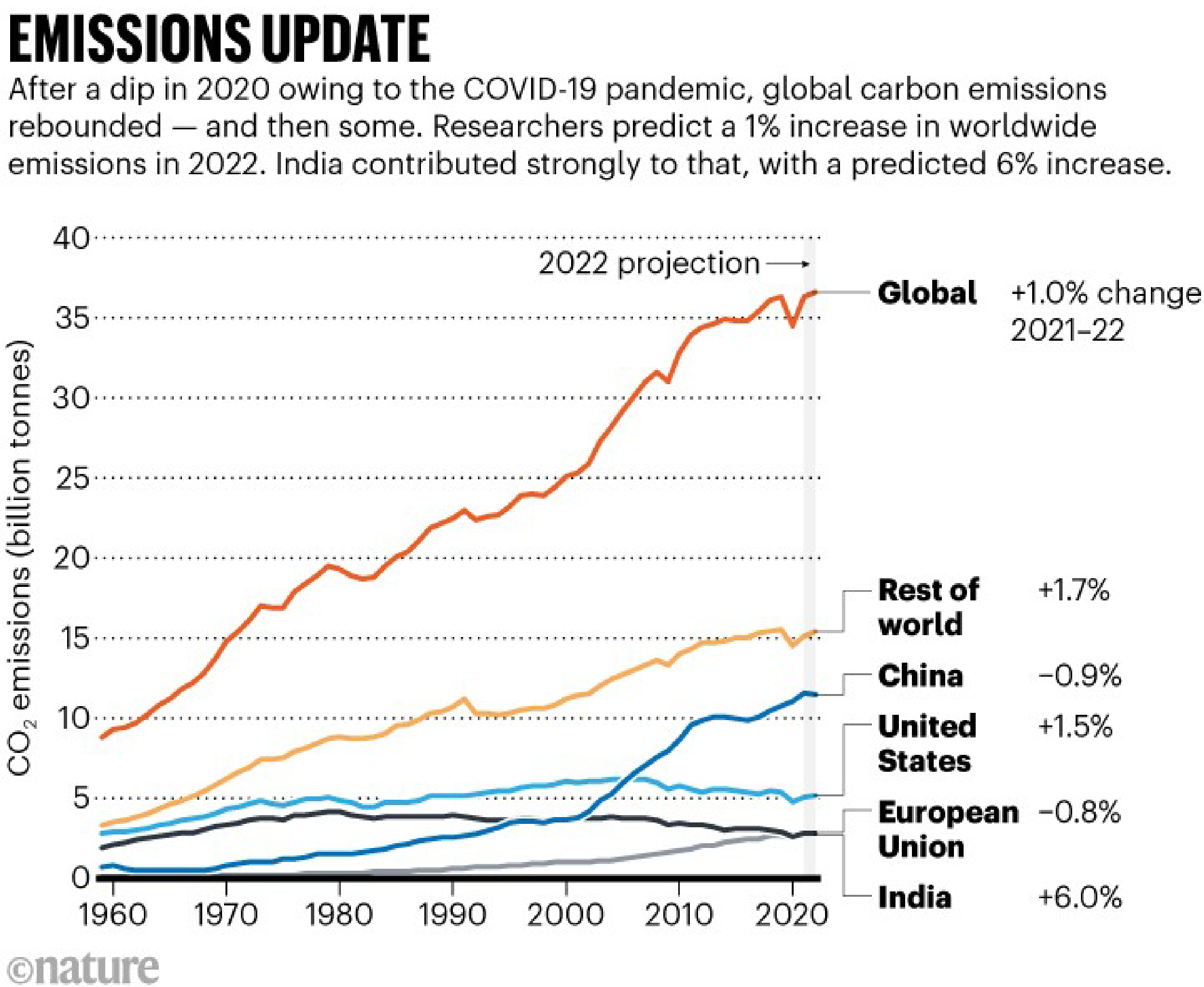
Given the magnitude of the efforts involved, there is a tendency to seek top-down government-driven efforts to address the investment requirements. However, such efforts cannot rely exclusively on government or official institution through increasing targets and guidelines, clearance of environmental mitigation programs, tracking compliance arrangements. While they can be bureaucratic and complex to manage, they can help in some circumstances, particularly when institutional capabilities are strong, when decommissioning or complex repurposing existing investments are needed. On the other hand, they can be problematic where institutions and accountability are weak, and thus pose a particular challenge in emerging economies.

Much of the effort may be needed in strengthening the policy environment, particularly for investments. Other things being equal, if incentives are right and the business is profitable, funding for investments is bound to flow, and carbon mitigation is going to take a hold — there are, of course, other underlying prerequisites (such as the existence of capital markets elements, an investment-friendly policy context, etc.)

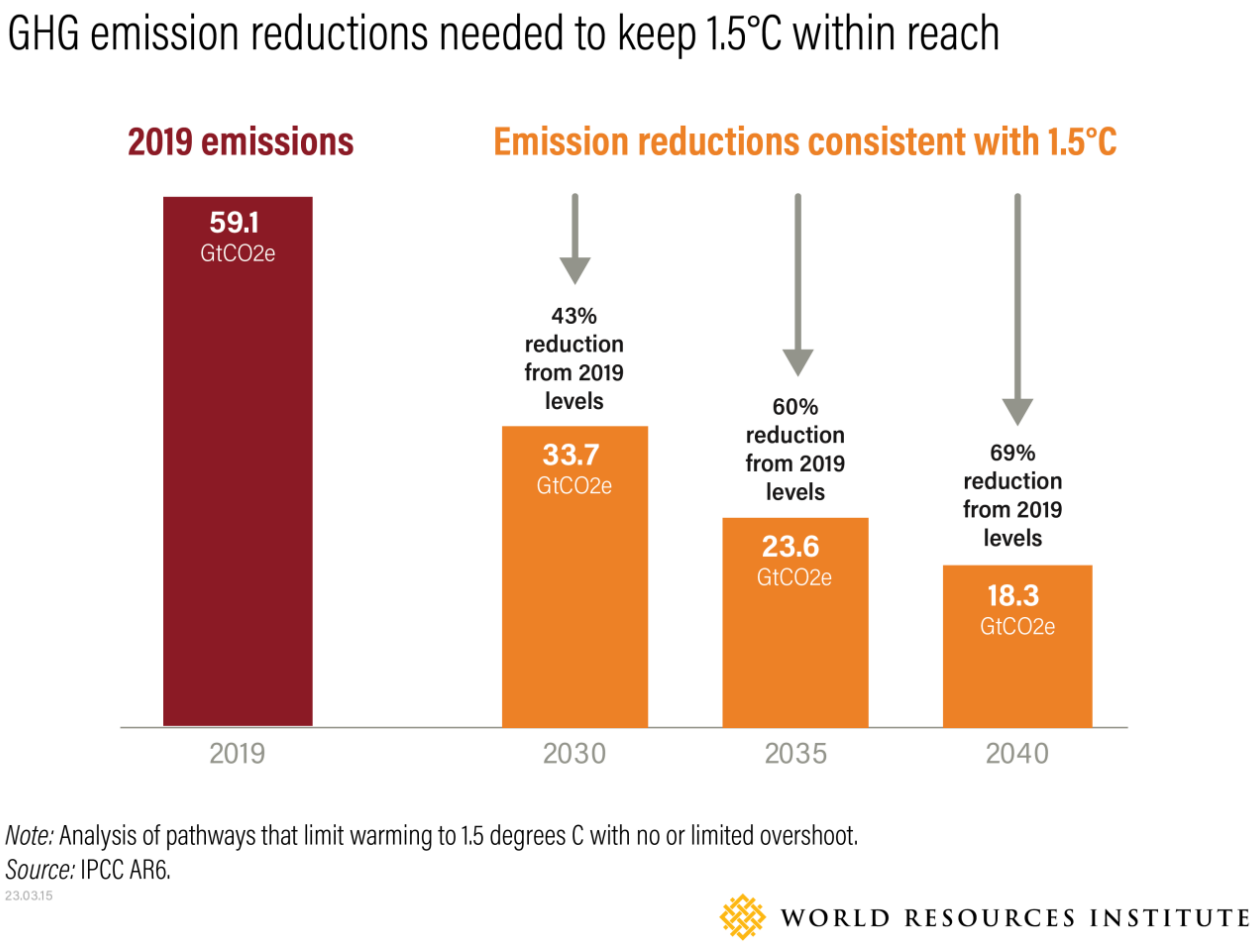
HOW ARE WE DOING; WHERE ARE WE FALLINGSHORT?--*Doubt is the father of invention* (Galileo)

It is always helpful (though at times sobering), to look at the goals that need to be achieved and the actual record of performance, to get a sense whether there is meaningful progress towards stated goals, the underlying quality of the programs that have been put in place, the way they are carried out and/or grounded on viable diagnoses of the issues being addressed.

Seen in that light, the Conference of the Parties (COP) tracking global carbon emissions basically indicate that carbon emissions remained basically steady at some 35 billion metric tons over the last decade, which of course compares favorably with the increases over previous decades (see graph below), but is a far cry from reductions needed to meet the Paris agreement goals. [4]



This in itself should alert us that what is required is nothing less than a fundamental change in the energy matrix. All this will call for much better performance in carbon reduction: than has been achieved so far, that only substantial Greenhouse gas (GHG) emission reductions to keep the 1.5C goal within reach, as can be seen in the graph below



So far, much of the changes in GHG emissions have been related to overall economic activity, rather than outcomes of carbon reduction policies. In 2020, for instance, global CO_2 emissions from fuel combustion showed an unprecedented decline of nearly 6% as the COVID-19 pandemic slashed global energy demand.

In all, though, fossil fuels still represented 80% of the total energy supply globally, with oil comprising 29%, followed by coal (27%) and natural gas (24%). Global emissions from fuel combustion were dominated by coal (45%), followed by oil (32%) and natural gas (22%). Under these conditions, three areas merit special attention.

First; the record seems to suggest that decarbonization goals may well be within reach in the more developed economies, which are increasingly moving towards service and value-added activities, often-times shedding industrial activities to emerging nations. Levelling of overall emissions have thus largely taken place in the US and the EU, and a more effective effort will be needed in changing the energy matrix to achieve the reductions envisioned in international agreements.

The effort will be more complex, and thus require more fundamental actions in emerging and industrializing countries, particularly in China and India, where emissions are still growing at a fast pace, given their continuing industrialization and integration to monetized economies.

Second; the goals and climate actions that are agreed tend oftentimes be taken at levels far removed, if not actually delinked, from "real life" realities on the ground, be it citizenry or industries.

Second; this has led to "solutions", without the slightest concern or knowledge of what final consumers want or need. No technical fixes, or push for certain aggregate goals is going to be effective or sustainable, unless it provides an adequate response to consumers' needs, a proper transition, and enterprises have a clear framework and incentives to operate and invest. In the end, it is at the kitchen table and the tightening purse strings that are the real drivers shaping emerging political alignments. It is difficult not to see the glaring gap between goals and achievements in the energy and environment debate at governmental levels, with the more here-and-now concerns on energy affordability, security, and sustainability at household levels – and the tensions that are being built in the streets and public arena throughout much of the world.

Third; in view of the foregoing, given institutional weaknesses in emerging economies, top-down vehicles for planning, regulation and execution can be particularly vulnerable to imprecisions, discretionary actions that open conditions for corruption, and time-consuming processes that oftentimes exceed periods of execution. Accordingly, some form of pricing will be helpful to generate the incentives to attract resources to where they are needed. As long as externalities are not priced, in effect giving them out for free, it is difficult to "bring home" the impact of inaction. There are many ways of pricing emissions — from pricing them directly, instituting taxes to act as proxies for the cost of emissions, instituting industry standards akin to the Equator Principles, establishing various forms of regulations ranging from direct monitoring and public oversight all the way to accounting conventions requiring enterprises to recognize in contingent liabilities the environmental damage they may generate. Each of these options have trade-offs and institutional requirements that need to be assessed before implementation.

MANAGING THE TRANSITION--*there is always another taller mountain;* 總有一座更高的山 (Chinese proverb).

It has been over 30 years since the UN Framework Convention on Climate Change. Since then, numerous Agreements have been reached (including the historic 2015 Paris Accord), 27 COP meetings have taken place, pledges made, reports written, and yet little tangible evidence of progress, as far as one can tell, can be seen in the climate change agenda and results.

Various documents, including the recent IPCC Experts' Report unequivocally confirmed that we are already seeing negative impacts of rising sea levels, droughts and extreme storms. Much more progress is needed to "move the needle", particularly in the power sector, which absorbs more primary energy than any other sector. Leaving political correctness and finer points aside, the paucity of progress should be a warning that something is significantly amiss.

This paper is an attempt to point at some obvious issues: the inability and bureaucratization of oversight institutions in effectively tracking and supporting the necessary corrective actions; the lack of enabling conditions to mobilize human and financial resources for proper investments in this area; the enormous costs and risks involved in the face of binding fiscal constraints, overstretched indebtedness that leave little room for surpluses for investments in the climate change agenda; the need for much better understanding of the cyclical nature of economic and associated issues affecting proper policy-making for climate and economic management issues.

While the challenge is immense, it is not un surmountable. It requires common sense, which is the less common of the senses, and a sharp focus on actions that respond to societal needs, including development, and thus incentives and accountability to produce results.

So much of the climate change debate has become deeply emotional and inflammatory, rather than open-minded and probing. The point of this paperisn't to take sides in what quite often are complex disputes. The lack of progress should in itself, however, be a warning that we are on a trajectory that is far from decisively correct.

Fighting global warming requires a broader and more nuanced understanding of how different sectors interact with each other. Merely adopting new environmental laws, creating new commissions or environmental regulatory institutions, pushing for particular technological fixes, or launching another 'campaign' will not get the job done. Judging by the record so far, it appears rather unlikely that the goals that have been agreed are going to be achieved. Much can be accomplished with existing technologies. However, without game-changing approaches towards policy, scientific or technological, and financial dimensions, the climate challenge is unlikely to succeed. This will require tackling these issues more specifically:

II. The Policy Gap

As nations look to lower their emissions, they are simultaneously facing increasing energy demands of a growing global population and increasing economic activities, particularly in emerging countries. Reconciling both objectives requires a policy framework that properly integrate civil society and industry concerns – i.e., this cannot be seen as a race to renewables, but race to reduce carbon emissions across many fronts. Investment trends in recent years, however, have contributed to the situation we see today. Unbalanced and underinvestment in the sector inevitably lead to price hikes. For too long, the sector has not developed the resources and back-up to enable it to respond to changes in supply routes and upticks in energy demand.

For all the seductive talk about the new economy and technological development, one cannot easily overcome the gravitational pull of traditional technologies (including the much-maligned combustion engine and associated fossil fuels), whose sunk costs make them highly competitive when compared with the resources and risks in new production platforms. Resistance to new approaches cannot be belittled, since their increased costs and reliability inherent in emerging technologies need weighing against their risk implications on economic development, which are particularly challenging in lower income countries.

Global energy policy discussions in recent years have focused on the importance of decarbonizing the energy system. The market (particularly civil society and industry) reminded though that this transition that it also needs attention to affordability, security, and sustainability that energy systems need to address coherently, rather than solely as an environmental or decarbonizing objective per se.

In the after light, over-reliance on any one kind of fuel or supply route leaves nations and the global market vulnerable to disruption, and that is what we have seen in recent years. Underinvestment in traditional energy (and inability of renewables to provide the required energy base to respond to increased demand, or provide reliability under changing weather conditions)has dragged global energy security and put strain on the energy transition.

Renewable forms of energy will play a growing role, but oil and gas are likely to remain an essential part of the energy mix for some time to come. While this may be an uncomfortable reality, it remains an undeniable fact, which recent years have brought to light. We cannot make a success of this transition if we neglect the foundations upon which industries stand – until the energy matrix has been radically changed, which inevitably will take long years to develop.

In part this is a symptom of a larger dysfunction -- the failure of policies to properly link incentives and emerging concerns on externalities, so that investments and consumption on the one hand, and supply response, on the other, respond to the delivery of public goods and private services demanded by society.

If international experience has anything to teach us, in the end each country will need to develop its own institutional infrastructure (for energy, transport and other sectors) to have a strategic framework on environmental concerns to face the development challenges of the years ahead. In doing so, however, oftentimes countries have inadvertently introduced competing and duplicative policies: operating at the national, regional (EU for example) and the international levels (leading, for example, to setting up over 15 different climate change ODA funds in the 2015's). The establishment of distortionary pricing policies and subsidies, led to difficult to reconcile conflicting signals, such as earmarked taxes on carbon trades to fund adaptation: taxing one public good (that governments want more of) to pay for another, and the establishment of earmarked funds to overcome distortions created by some funds or subsidies.

Governments will thus need to remain vigilant to avoid developing institutionally-intensive arrangements in institutionally-weak environments, since "institution-building" mentioned in the Paris Agreement is a long and difficult road. Wherever possible, policy frameworksmustenable key economic actors to interact organically, without too many constraints and avoid complicated regulatory systems (where duplication, offsetting incentives, etc.) all too often become a constraint to investment and development.

The rule should be to minimize the rules, and use pricing where at all possible, while allowing legitimate additional costs of compliance to environmental standards to be recouped through output prices — thereby avoiding energy development paths becoming costly and complicated.

From an energy perspective, recent disruptions to Russian energy supplies and consequent energy shortages seem likely to have had material impact on the energy system. The desire to bolster energy security by reducing dependency on imported energy (dominated by fossil fuels)by developing domestically produced energy, coming from renewables and non-fossil energy sources, suggest that the conflict may well accelerate the pace of energy transition.

On the other hand, the scale of the economic and social disruptions associated with the loss of just a fraction of the world's fossil fuels also highlighted the need for the transition away from hydrocarbons to be orderly, such that the demand for hydrocarbons falls in line with available supplies, avoiding future periods of energy shortages and higher prices.

In this regard, the lack of foresight, the low energy security of existing energy matrix, and the consequent crisis triggered by the conflict in Ukraine have prompted the 51 largest economies to double support for fossil fuels to almost $700 billion in 2021, and even larger amounts in 2022 -- mitigating energy price increases for consumers, and generating incentives for increased fossil fuels supply to achieve a quick response to overcome the crisis. This undermined removal of inefficient and distorting subsidies, undercutting environment friendly policies and pledges.

The consequent International Energy Agency (IEA)finding of 42 economies noted that consumer support increased to $531 billion in 2021, more than triple their 2020 level, driven by the surge in energy prices. Careful and planned investment in both renewables and hydrocarbons is thus essential for an effective energy transition.[5]

One hopes that with greater transparency on massive subsidies and associated misallocation of resources, corrective action could be seriously considered to get proper resource allocation towards the energy transition and the climate change agenda. Hiding in plain sight, the missing trillions for climate change are highlighted in a World Bank report, Detox Development: Repurposing Environmentally Harmful Subsidies. It shows the extent of global subsidies and the opportunity offered by repurposing them. Compared to what countries pledged in the Paris Agreement, every year, they spend about six times that amount to subsidize fossil fuel consumption, which in turn exacerbates climate change, toxic air pollution, inequality, inefficiency, and mounting debt burdens. Redirecting these subsidies could unlock at least half a trillion dollars per year towards more productive and sustainable uses.[6]

III. The Technological Gap

It is a forgone conclusion that, as in other fields, technology will evolve, increasing their capabilities, doing so at declining costs, thereby being an increasing part of the solution of climate change concerns. That said, one must keep an eye on: (i) societal demands that must be addressed in devising proper energy supply responses, and inherent limitations to address market demand that that need to be addressed with supplemental investments; (ii) the nature of climate change issues that involve impacts across broader supply chains, including externalities generated across sectors; and (iii) the technical choices and speed with which decarbonization efforts can be introduced.

On the societal elements, it may be appropriate to recall that many, if not most, of the approaches used in technological approaches are a relic of a bygone era. The tendency to choose particular approaches (i.e., solar, wind or other) are grounded on the assumption that Authorities know better what is good for people, and that environment benefits accrue to the direct user, or their neighbors. Yet, CO2 emissions are invisible, and impact in the seemingly distant future. They actually go to the atmosphere, thereby affecting the global or worldwide (rather than solely to local) community.

Not surprisingly, there is limited consciousness or genuine groundswell constituency for CO2 emission reductions, and limited understanding of the impact or options, such as reducing waste, cutting meat consumption, taking fewer round-trip flight, reducing home electricity usage, living in car free environments, and/or purchasing carbon offsets. Actually, all research surveys done on the subject reveal that people "don't have much of a clue".

The introduction of renewables that generate energy without fossil fuels, and avoiding carbon emissions, makes intuitive sense. In practice, though, this approach is not without its share of constraints – chief among them is their heavy dependence on location and climate conditions, thereby becoming useful if properly backed up by traditional sources, so that they can deliver reliable energy supply(during evenings, in bad weather conditions, etc.), particularly for industries that require high load factors for their production. In fact, we cannot talk about solar or wind without also talking about its land-use or coastal areas and grid implications, the reserve capacity that will be needed to overcome the intermittent nature of most renewables, and the investments needed to overcome such constraints, which are an inherent part (and cost) of the seemingly "free" feedstock of such options.[7] In the end, making informed and well-grounded decisions will have to be rooted in making the invisible, visible.

By the same token, decarbonization efforts in transportation via electronic vehicles (EVs) will not cut emissions to zero by itself – not until we have also decarbonized the steel used to make them, and the electricity that powers it (which otherwise would just move the emissions upstream from the refilling stations to the power generating plants). But it at least holds the potential to be a significant part of solution, if properly addressed through the supply chain – though, again, with their attendant share of costs.

Assessing actual decarbonization impacts thus need to focus on the full supply chain. Inputs required to produce low-emitting power generating facilities, require large quantities of rare earth elements, critical minerals and metals whose production comes from art-to-abate mining activities. To achieve the agreed global temperature goals will require a major uptake of wind turbines, solar panels, electric vehicles (EVs), as well as storage batteries — all of which are made with rare earth elements and critical metals, which include 17 rare earth elements, the 15 lanthanides plus scandium and yttrium. Elements such as silicon, cobalt, lithium, and manganese are not rare earth elements, but are critical minerals that are essential for the energy transition.

The demand for rare earth elements is expected to grow 400-600 percent over the next few decades, and the need for minerals such as lithium and graphite used in EV batteries could increase as much as 4,000 percent. Most wind turbines use neodymium–iron–boron magnets, which contain the rare earth elements neodymium and praseodymium to strengthen them, and dysprosium and terbium to make them resistant to demagnetization. Global demand for neodymium is expected to grow 48 percent by 2050, exceeding the projected supply by 250 percent by 2030. The need for praseodymium could exceed supply by 175 percent. Terbium demand is also expected to exceed supply. And to meet the anticipated demand by 2035 for graphite, lithium, nickel, and cobalt, some analyses project that over 380 new mines would be needed.

Similarly, copper is bound to become a foundational metal for the energy transition, electrification, and global growth, and demand may well double by 2035.According to some estimates, there will not be enough supply to meet the demand of Net-Zero-Emissions by 2050. At current levels of technological development, most mining activities constitute hard-to-abate sectors, and considerable technological work will be needed to ensure that mining can reduce emissions so that the supply chain, in its entirety, can respond to the CO2 emission reduction goals.

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This is a tall order oftentimes overlooked. Supplying these vast quantities of such minerals in a sustainable manner will be a significant challenge, but scientists are exploring a variety of ways to provide materials for the energy transition with less harm to people and the planet than currently possible with current level of development.

Seen in this light, as already alerted by some IPCC members, greater attention should be focused on options being promoted that are grounded on "technological optimism", which require better scientific validation in terms of their full-cycle implications. An example that illustrates his point on how biodiesel allegedly lowers emissions, when it actually could generate up to twice the CO2 emissions when considering the deforestation necessary to produce the soy for fuel production.

Finally, on technical choices and the pacing of reforms, there is a lot to be learned from the various experiences being instituted around the world. It would be most helpful to review such experiences in terms of the impacts, cost, institutional requirements, etc. so that learning and optimum investment patterns can be embedded early on in ongoing efforts taking place worldwide.

In Germany, for instance, the widely applauded fast transition into a green economy and CO2 neutrality by 2050 or even 2045 will be extremely expensive. A study by Prognos for the public bank KfW estimates that it will take private and public investments in the amount of some 5,000 bn EUR in order to reach climate neutrality by 2045. It will be an open point for discussion why cheaper solutions for climate change adjustment or CO2 abatement abroad may not be pursued.

In Germany, the present transition of energy production as fixed by laws is loaded with problems, as there must be a replacement of the power generation facilities running on uranium or coal (hard coal and lignite), which are in an accelerated shut-down process. The only viable alternative is an interim switch to natural gas as a back-up energy for electricity generation; notwithstanding the increasing power demand from digitalization, E-mobility, and conversion of heating systems, there is a need for at the least an additional 70 GW of gas power. This increases the dependence on natural gas imports.

IV. The Informational Gap

It is difficult not to see the gap between actions to address environmental problems and energy transition and the absence of tangible results. Ultimately, the problems seem to center on the fact that actions can only be taken at the local or national levels, and the implications ultimately yield at the global level. In other words. As long as the companies or individuals) that generate greenhouse emissions do not see the costs and obtain the benefits that they generate, it is unlikely that the corrective action will be proportional to what is needed. No amount of regulatory enforcement or international agreements can easily overcome this basic gap.

Trying to "manage" this disconnect via the regulatory route has inevitable constraints, particularly when costs and benefits occur throughout supply chains, which cross a multitude of sovereign nations. Trying, for instance, to reduce emissions by electrifying transportation through electric vehicles (EVs), even within the confines of a single country, is bound to have its limits, as long as power generation is not decarbonizedas well. Otherwise, emissions are only being transferred "upstream" to the power sector, where the resulting increased demand from EVs may well be met through increased fossil fuels-based power generation.

Furthermore, given the enormous scale of compiling emissions figures, which influence environmental policy and investment, particularly in solar energy, given the difficulties in collecting information from China. In fact, some sources, estimate the footprint of solar PV to be higher than current models used by the IPCC, even when compared to natural gas, with carbon capture.[8] It is thus hard to assert in a reliable fashion how much solar PV installations will reduce CO2 emissions.

In the absence of reliable primary-source or verifiable data, it would not be unreasonable to assume that China's competitive advantage in solar technology, with which they have conquered a large part of the world market, does not lie in a new innovative technological process, but rather in the same factors that the country has always used to overcome the production costs of Western countries: cheap coal power, massive government subsidies for strategic industries, and low cost human labor operating in poor working conditions. Similarly, when assessing the interaction between risk and resilience in the face of climate change, analysts are similarly hampered by tracking though accounting practices that track the symptoms, rather than the root causes of the of climatic calamities. [9]

V. The Financing Gap

Bearing in mind the cumulative climate, health, energy and inflation crises have put on advanced and developing economies alike, the accumulated fiscal deficits and growing public debt have led to growing calls for a fundamental rethink of how the public sector supports and system for multilateral development finance should adjust to respond to increasing demands, particularly in low- and middle-income countries.

Hitherto, much of the focus of discussion and policy-making has centered on public sectors around the world, and as a result, efforts have centered too much on overstretched governments that have hardly the wherewithal and resources to appropriately address the climate change issues in an effective manner. Support has unfortunately been rather ad hoc and reactive to the crises as they developed, particularly in Europe, as described above.

In light of inevitable limitations and conflicting claims on public sector resources in developed countries, the Multilateral Banks (MDBs, particularly the World Bank) must step up and revisit more aggressively their specific role in closing the climate and energy transition finance gap – both directly, and supporting much needed enabling investment and resource mobilization conditions. This would need to be done by "leveraging" more proactively their other essential roles in provision of development finance, up scaling their relationships with other institutions providing private and public climate finance, including the IMF's Resilience and Sustainability Trust (RST), and mainstreaming their technical assistance and policy advisory role to borrowing countries.

To some up, the scale of global financing required to meet mitigation and adaptation needs is vast, to say the least: $9 trillion of climate investments each year through 2050 – of this, $6 trillion for repurposing finance that would otherwise go to high carbon assets; $3 trillion per year for new spending in incremental capacities.

However, the climate and energy transition finance situation in many low income and emerging economies remains extremely serious. Much of the finance in such countries will be needed for adaptation infrastructure. However, many of them face compelling and competing claims for public finance to meet education, health and social needs. They also have low tax raising capacities with low revenue to GDP ratios, and the availability of both public and private finance from global sources is limited by the already high, and rising sovereign debt distress. Today 15% of low-income countries are already in debt distress, while a further 45% are at high risk of debt distress.

Multilateral development banks' contributions can be leveraged by: (i) providing technical and analytical support for improving the overall policy and technical context for marshaling climate finance; (ii) lending directly to sovereign governments to improve policy and finance individual projects and improving the environment in which other publicly or privately financed projects can take place; (iii) integrating their respective private sector arms – such as the International Finance Corporation (IFC) and Inter-American Development Bank's IDB Invest to lend or invest directly in private companies in developing countries; underpin private financial flows to climate mitigation and adaptation projects by taking on some of the risks that the private sector is not willing or unable to bear, through provision of insurance, guarantees, or more complex risk sharing arrangements; promote innovative climate financing techniques in international capital markets by demonstrating what can be done and how to scale it.

As climate change is a global (not a local) issue and emissions have to be reduced to clip greenhouse effects in the atmosphere, it is difficult to "sell" locally the sacrifices to reduce global climate warming, as long as those concerned cannot see, tangibly, the effects of such efforts they need to undertake. As long as externalities are not priced, in effect giving them out for free, it is difficult to "bring home" the impact of inaction.

There are many ways of pricing emissions — from pricing them directly, instituting taxes to act as proxies for the cost generated by emissions, instituting industry standards akin to the Equator Principles, establishing various forms of regulations ranging from direct monitoring and public oversight all the way to accounting conventions requiring enterprises to recognize in contingent liabilities the environmental damage they may generate. Each of these options have their trade-offs and institutional requirements that need to be assessed before implementation.

Given the scale and the pivotal role that the private sector is bound to have in mobilizing the increasing human, technical and financial resources needed to address the changes needed to meet the international agreements, the question that remains to be fully flushed is whether organized voluntary carbon markets can help resolve these challenges by creating credible incentives for emissions reductions, and mobilizing the corresponding resources and incentives to resolve the climate change issues.

The global voluntary carbon market, and its supporting industry ecosystem, has grown substantially from its origins in the early 1990s. Despite this growth, voluntary markets have been hampered by reputational and functional concerns about offset quality and the space remains fragmented.

With no long-term regulatory, institutional obligations or pricing signals on carbon, firms are left to chart their net-zero paths with little guidance or policy vision. The question is whether organized voluntary carbon markets can help resolve these challenges by creating credible incentives for emissions reductions.

Recent initiatives aimed at creating more functional, transparent, and effective carbon marketplace are a good start. In many cases, there is a growing intersection between government and private sector activity in voluntary markets. governments and/or industry regulating processes could support the legitimacy and success of voluntary markets.

These novel initiatives demonstrate how market design choices imply different goals for voluntary markets. These models suggest new ways for to manage increasing demand for carbon credits, private firms and organizations have developed standards and maintained credit registries.

Today these are well-established players such as the American Carbon Registry (ACR), the Climate Action Reserve (CAR), the Gold Standard (GS), and the Verified Carbon Standard.

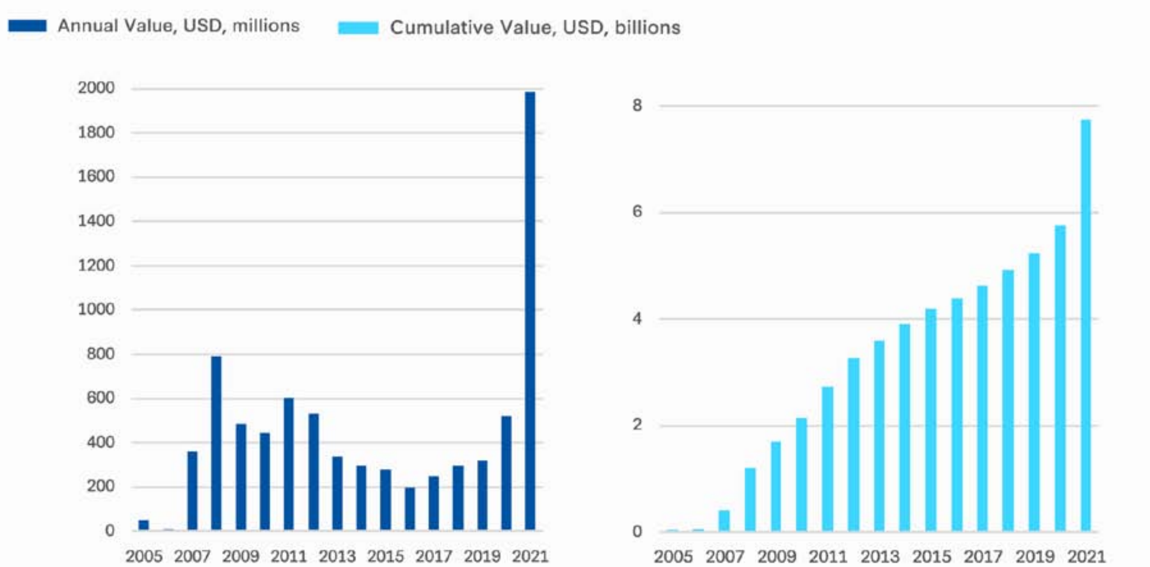
These agencies regulate the "supply" side of the market; they define project standards, verify compliance, and host registries that regulate the minting and retirement of credits. It is important to note that these remain nongovernmental and private; they earn revenue from the offsets they recognize.

While the current voluntary market ecosystem is fragmented and dominated by decentralized, broker mediated, over-the-counter trades, there have been previous attempts to organize and regulate the space. In 2021, its market value reached nearly $2 billion, marking impressive growth from less than $200 million just five years prior.

The 2016 Paris Climate Agreement has created new opportunities for voluntary carbon markets. Article 6 of the agreement raises the possibility of countries using carbon offsets toward their Nationally Determined Contributions (NDCs). This provided official recognition of the offset model and the value of voluntary markets, pointing toward a future in which they could achieve international standardization. equivalent to that of large-scale compliance markets.

They thus can be seen as a critical tool for mobilizing finance for climate mitigation. However, the present global voluntary market, composed of unregulated demand, bespoke fractured trading systems, and a vast sea of heterogeneous supply, has demonstrated limited ability to deliver a price on carbon that The convergence between private carbon markets and governments, as well as the need to scale the trade of high-quality credits, has resulted in a number of new market initiatives, and growing activities through global voluntary carbon markets, as noted below:

Figure 1: Global Voluntary Carbon Market Size by Value of Traded Credits



Source: "Market Size by Traded Volumes of Voluntary Carbon Credits, Pre-2005 to 31 August 2021," Ecosystem Marketplace, https://data.ecosystemmarketplace.com/.

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Various models show that voluntary efforts can be supported by state or other forms of collective validation to add credibility and centralization, which signal long-term recognition of the market as integral to achieving national climate goals.

Clearly, it is here where institutional development to build up from the experience so far, will be required to develop genuine carbon markets, to help mobilize resources where they are needed with the necessary validations. Hitherto, carbon market has historically been dominated by avoidance credits (i.e., projects that avoid emissions that otherwise would have occurred, such as preventing deforestation or building renewable energy where fossil fuel-fired resources would have been built). Challenging these are a new class of removal credits that certify direct removal and sequestration of carbon dioxide from the atmosphere. Further, the emissions reduction contribution is considered more scientifically rigorous relative to avoidance credits. Increasing the supply of carbon removal credits is seen as a critical component in meeting net-zero goals. These factors combine to allow removal credits to command a premium from buyers and trade at many multiples of avoidance credits.

VI. Conclusion

The battlefield is a scene of constant chaos. The winner will be the one who controls that chaos, both his own and the enemies(Napoleon)

It is hard not to be puzzled by the obvious contradiction that can be seen in energy transition. On the one hand, taking at face value pledges, programs, goals articulated in COP meetings, it would seem that we are on our way to reach the 1.5°C climate target by mid-century. On the other, looking at actual, and the immensity of the infrastructure, policy and regulatory enabling issues to be addressed, it seems that the goals are illusory, and that we are barely prepared for a decisive move "from words to deeds".

Clearly, the confluence of a series of crises, almost in tandem, have overstretched the governance institutions that have been built for more stable and different times. The geopolitical conflicts for global preeminence between existing and emerging powers, the spread of the pandemic, growing dissatisfaction of civil societies with the distribution of opportunities and benefits of economic progress, have strained the capacity and imagination of all major actors leading governments.

The time has come to recast the overall global financing and governance architecture to mainstream key multilateral institutions (including World Bank and others), and draw-in private sector actors. MDBs have become notoriously bureaucratic, slow-moving, unresponsive to emerging demands, and require vehicles for transparency and accountability to properly respond to emerging needs without complicated multilayered and duplicative decision-making processes. Such change will be essential to rebuild stakeholder (and shareholder) confidence to facilitate improved and results-oriented resource use, and thus preparedness to support their mandates and management of their resources.

By the same token, the problem of climate change is going to be solved by innovation and entrepreneurship, more than by governments and politicians. This is in essence the role of the private sector, and the risk taking associated with it.

If societies are genuinely concerned about pollution, climate change, and are willing to let their purchasing decisions be guided to some degree by their concerns — to put their money where their mouths are, to put it crudely — then they can generate incentives to which the corporate world and civil society will respond, while accommodating lower income countries and population to manage their transition.[10]

Aware of such limitations, various Governments are working on actions aimed at overcoming at least partially the absence of carbon markets. The EU has established a Carbon Border Adjustment Mechanism to partially reflect to a price on the carbon emitted during the production of carbon intensive goods that are entering the European market, and to encourage cleaner industrial production in non-EU countries. Other countries, like Chile, have introduced pricing and taxation practices aimed at reflecting environmental costs, as an interim measure until carbon market legislation is issued for a more market driven pricing system. Israel is working on various alternatives to introduce some form of carbon pricing vehicles,

In the case of the US, a deliberate hands-on policy seems to be taking shape aimed at pulling innovation, driving costs down while creating jobs within the country, and supporting specific industries that are considered foundational for economic growth, strategic from a national security perspective, and where the private sector is not considered to be poised to undertake investments on its own. To this end, an Inflation Reduction Act was enacted to support US production of some products (like EVs), to onshore and friend-shore supply chains to reduce dependence on major competing countries like China, and institute tax credits to generate demand for transportation electrification and other such activities in the US. As in any directive approach aimed at several objectives in tandem, it remains to be seen how effectively the industrial policy, environmental and geopolitical objectives can be reconciled in an effective manner, and what geopolitical ramifications it may have.

Perhaps, the International Renewable Energy Agency has pretty much encapsulated the thrust of this discussion when noting that"a profound and systemic transformation of the global energy system must occur in under 30 years", underscoring the need for a new approach to accelerate the energy transition. Pursuing fossil fuel and sector al mitigation measures is necessary but insufficient to shift to an energy system fit for the dominance of renewables-- "the emphasis must shift from supply to demand, toward overcoming the structural obstacles impeding progress…through policy and regulatory enablers and well-skilled workforce, requiring significant investment and new ways of co-operation in which all actors can engage in the transition and play an optimal role."

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Ageing of Nuclear Power Plant's Equipment. Assessment of Reactor Pressure Vessel Ageing Effect

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Abstract- Ageing of materials stands for the change in their mechanical properties, due to thermodynamic imbalance of the initial condition, and gradually bringing the structure to equilibrium in the presence of sufficient diffusive mobility of the atoms. The current paper presents the main mechanisms of degradation of the mechanical properties of the nuclear power plant equipment metal, as well the models for ageing. The ageing effects and ageing indicators typical for the equipment are defined. The ageing process may cause loss of the appropriate functions. It is important to recognize the ageing effects, as well the ageing indicators. Testing methods are defined for every ageing indicator.

The paper considers different national approaches to ageing management of structures, systems, and components (SSCs) at nuclear power plants (NPPs).

Keywords: *nuclear power plant, ageing, assessment of ageing, long term operation.*

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AGEINGOFNUCLEARPOWERPLANTSEQUIPMENTASSESSMENTOFREACTORPRESSUREVESSELAGEINGEFFECT

Strictly as per the compliance and regulations of:

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The paper considers different national approaches to ageing management of structures, systems, and components (SSCs) at nuclear power plants (NPPs).

An approach has been suggested to study the effects of ageing of reactor pressure vessels (RPV). Assessments have been performed on the ageing effects of reactors as a result of load factors such as radiation and thermal impact of the neutron fluence, corrosion impact of the primary circuit fluid, hydraulic and thermal impact of the fluid.

Keywords: nuclear power plant, ageing, assessment of ageing, long term operation.

I. Introduction

Atoms build up matter and are a source of a great deal of energy. Atomic energy today is used for electricity generation, medical and scientific research, or for exploring of submarine and cosmic worlds. There are over 441 nuclear reactors in operation worldwide. A plant's operating life for a specified service-time period is justified by the required strength margin [1]. Normally, the operating design life of nuclear reactors is 30-40 years [2]. As at April 2022, of all the reactors in operation, 133 had been operated for over 40 years, while the service life of another 164 had exceeded 30 years.

Often the owners of Nuclear Power Plants (NPPs) make decisions to extend the plant life of the power units: these capacities are the source of various benefits for society such as cheap electricity, energy independence, jobs, knowledge and technological development. However, in the operation of Nuclear Power Plants and particularly the older ones, the level of safety should not be decreased. In Japan, the following analogy is very popular: nuclear safety culture is represented as a person standing on the steps of downward moving escalator. The escalator embodies all load factors of the equipment, the resulting ageing of materials and design obsolescence, human errors, i.e., those contributors to the reducing of nuclear safety. In order to maintain one's position on the escalator, the person has to make constant efforts, while climbing upward requires even greater efforts. Continuous activities are needed to enhance safety culture. In the energy sector, the problem of ensuring the reliability of power equipment performance with each passing year is becoming more and more relevant, as the ageing of equipment significantly outstrips the pace of reconstruction and modernization of the operating capacities. This problem is further complicated by the absence of a scientifically grounded concept of technical diagnostics and lifetime determination, as well as by the inadequacy of traditional non-destructive testing methods.

The opportunities for design life extension of nuclear power plants are demonstrated through analysis, tests and adequate lifetime management for the expected long term operation [3]. Over the past decade, a growing number of countries have been putting the highest priority on the task of lifetime extension of nuclear power units.

This paper reviews the ageing mechanisms of the WWER type of equipment, ageing effects and the corresponding ageing indicators typical for the manifestation of these effects. Identification has been made of the control methods and indicators of function loss of the respective equipment subjected to ageing.

An approach has been proposed for studying the ageing effects on some of the most important nuclear power unit components, i.e., the reactor pressure vessels. Assessments have been performed on the ageing effects of reactor pressure vessels due to load factors such as radiation and thermal impact of the neutron flux, corrosion impact of the primary circuit fluid and hydraulic and thermal impact of the fluid.

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II. Overview of National Approaches to Ageing Management of Structures, Systems, and Components (SSCs) at Nuclear Power Plants (NPPs)

The technological development level of individual countries has produced different national approaches to resolve the problems of nuclear energy SSCs ageing management.

a) *Ageing Management Approach of French NPPs*

France has been reported to be one of the first countries that started dealing with the problems of ageing equipment at French nuclear power plants. During the 1980s there were three main lines of activity and survey [4]: 1) study of the physical process of degradation with a focus on the radiation embrittlement, 2) the behavior of elements and systems throughout the ageing processes due to thermomechanical and hydraulic impacts; corrosion in the primary and secondary circuits of the power plant, 3) preparation of reliability analyses and development of methods; adopting the understanding that operational experience (OE) serves as a source of data.

At present, France has 56 nuclear reactors in operation, and 14 ones have gone through a final shutting-down for decommissioning [4]. France's main program on the issues of ageing is under the jurisdiction of the French company Électricité de France (EDF) and is implemented in three main steps: 1) SSCs with an impact on the NPP safety, and affected by ageing, get identified, 2) analyses are conducted on the SSCs degradation, taking into account the possibility of maintenance of the facilities, the difficulties regarding the replacement of obsolete equipment and the risk of lacking a waste management technology, 3) detailed reports are written about some components susceptible to ageing (i.e. the RPV, reactor internals, buildings, computer and electrical equipment).

The reactor equipment is the hardest and most complex for replacement. The main degradation mechanism is neutron ageing of the material, yet ageing by this mechanism is "well managed" (according to the French power engineers) except under conditions of thermal shock. This event could cause brittle fracture of the reactor pressure vessel material. But such a scenario is part of the design of the French nuclear power plants, using special steels with chemical elements, such as copper and phosphorus that are naturally resistant to neutron embrittlement. These elements enable lower temperature values of elastic-to-plastic transition in the metal. Depending on how low these reference temperature values are maintained, it is possible to determine how ageing will be affected and to predict the performance value at the end of the design life of the reactor (i.e., after 40 years).

b) *Ageing Management Approach of the Hungarian NPP*

In Hungary, there are four WWER type of reactors (Paks Nuclear Power Station). The plant lifetime characteristics have been evaluated. The plant life has been extended by 20 years. A characteristic feature of the Hungarian approach is that a dedicated Hungarian regulatory basis has been developed, i.e., the Hungarian Guideline 4.14 [5], to deal with ageing issues. The ageing management programs include: 1) identification of degradation mechanisms and the affected component (SSC), 2) ageing mitigation and prevention measures, 3) specifying monitoring parameters, 4) detection of ageing effects, 5) monitoring and trending, 6) acceptance criteria of the evaluation results, 7) corrective actions, 8) feedback, effectiveness and improvements.

c) *Ageing Management Approach of the Spanish NPPs*

Spain has seven nuclear reactors. The Spanish approach regards the SSCs ageing management as a process that requires periodic re-evaluation and upgrade. A major source for streamlining the process is the feedback from operating experience. Many of the changes to the Spanish NPP ageing management programs concern the SSCs maintenance activities, e.g.:

- Preparation and verification of a new guide book on SSC maintenance activities, with a focus on the conditions of accessibility to the equipment.
- Training practice in duty tours and walkdowns.
- Improving the identification of structural components.

The mechanism of flow accelerated corrosion (FAC) is turning into a challenge to the ageing management process, as a large part of the carbon steel equipment necessitates replacement. Another growing issue is that of inspection and control of some concealed underground (buried) pipelines, due to difficulties in using standard tools. Studies are focused on search of new technological solutions.

d) *Ageing Management Approach of the NPPs in the Czech Republic*

The Czech Republic operates six nuclear power reactors. The Czech methods and criteria for identifying SSCs within the scope of ageing management require:

- Summarizing the data on equipment ageing.
- Conducting of assessments and documenting potential mechanisms for properties degradation that could affect the safety functions.
- Continuous activities to expand the current understanding of all the dominant mechanisms of ageing.

- Availability and adequacy of the data needed for ageing assessment, including design basis data, and maintenance and repair data.
- Implementing effectiveness evaluations of the maintenance and repair programs in terms of ageing.
- Identifying criteria and indicators for safe operation over the long-term operation (i.e., operation beyond the design life term).
- Conducting assessments of the physical condition of SSCs, including the current safety indicators and conditions that may limit the operation lifetime.

The ageing management of SSCs important to safety requires that degradation be controlled in accordance with specified criteria. Effective control of the ageing degradation is needed through systematic assessments of maintenance and repairs, so that this may result in minimization of ageing trends, and preservation of the integrity and functional capabilities of the SSCs.

e) Ageing Management Approach of the NPPs in Canada

In Canada there are 19 reactors in operation of the deuterium-uranium unit type (CANDU). In the equipment screening process, two categories of components have been identified: critical components and less critical ones [6]. The following actions are taken in the course of the ageing management process: 1) assessment of the plant lifetime characteristics of critical non replaceable equipment (mainly passive equipment), 2) systematic assessment of the maintenance actions for critical SSCs through analyses of the operating states (modes) in which failures occur, 3) condition assessments for less critical equipment components, and for the remaining SSCs.

The types of critical non replaceable equipment subject to ageing management include: fuel channels, steam generators, reactor units, reactor building and civil buildings, pipelines, turbine generator, pumps and heat exchangers, electric motors, breakers and cabling systems, pumps and buildings.

The less critical components and equipment have been allocated in groups per some typical characteristic, i.e., commodity groups (pumps, tools). Each group undergoes specific operability analyses. The ageing management methodology includes:1) reviewing the entire operational history of the component, its design and fabrication in terms of ageing characteristic features, 2) diagnosing the ageing stress factors and the mechanism of properties degradation under all operating modes. Evaluating the component maintenance in terms of ageing management effectiveness.

f) Ageing Management Approach of the NPPs in the USA

The USA have 96 reactors. The components get assigned to categories based on their significance for the reliable and cost-efficient nuclear power plant operation. To this effect the following criteria are used: 1) ageing effect (potential one), 2) affecting the component's intrinsic functions, 3) identifying the corresponding ageing management activities to ensure that the expected functions of the components are supported.

The SSCs assessment is made on the grounds of NEI 95-10 guideline [7] and is in fact an integrated assessment of the nuclear power plant and a review of the time-limited ageing analyses for SSCs covered by the license. This integrated assessment of NPP consists of identification of the components' materials and their interactions with the environment, the applicable ageing effects that may impact loss of the anticipated functions, as well as a lifetime management program needed to support these functions.

The time-limited ageing analyses contain qualification for the environmental impacts, fatigue toughness and neutron embrittlement resistance analyses.

An element of key importance for the continuous improvement of ageing management at US nuclear power plants is the use of OE feedback together with incorporation of the lessons learned in the ageing management programs.

g) Ageing Management Approach of the NPPs in the India

The Nuclear Power Corporation of India Ltd (NPCIL) conducts the lifetime extension process of the Indian NPPs in accordance with its own NPCIL instruction HQI-7005, based on the IAEA Safety Specific Guide SSG-30 [8]. The main points of this instruction include, as follows: 1) SSCs screening and ranking as per level of importance of the NPP safety, 2) ageing methodology that comprises degradation effect and is based on the degradation mechanism, 3) evaluation of the SSC maintenance, 4) inspection of SSCs and degradation prevention techniques (maintenance, rehabilitation or replacement).

In terms of material properties degradation, the equipment has been allocated in four categories:

- *Category 1:* Major SSCs, of critical importance and limited lifetime.
- *Category 2:* Critical SSCs.
- *Category 3:* Important SSCs.
- *Category 4:* Other SSCs.

The regulatory system of India does not specify a limit to the time period for operation of an NPP. The power plants can continue operation as long as they

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meet the regulatory requirements and satisfy the safety measures.

h) Ageing Management Approach of the NPPs in China

The first Chinese NPP, Qinshan-1, entered in commercial operation in 1991. Since then, 15 WWER nuclear power units have been constructed and commissioned as well as PWR и CANDU ones.

Safety factors have been checked during each periodic safety review: 1) documented procedure and criteria for identification of SSCs impacted by ageing, 2) list of SSCs incorporated in ageing management programs, and records that this provides data in support of the ageing methodology, 3) evaluation and documenting of each potential degradation mechanism that may affect the safety functions of SSCs, 4) broadening of the understanding of the dominant ageing mechanisms, 5) applicability of data for degradation assessment including design data, historical operation and maintenance data, 6) effectiveness of the operation and maintenance programs in terms of ageing management of replaceable components, 7) availability of programs for timely detection and prevention of ageing, 8) acceptance criteria and required safety limits for SSCs, 9) informing about the physical condition of SSCs, including current safety limits and future events (any events) that may put limitations to the operating lifetime of the facility.

i) Ageing Management Approach of the NPPs in the Republic of Korea

The selected criteria for components affected by ageing and subject to lifetime extension involve a number of standards and normative documents including regulations for periodic safety reviews (PSR), US regulatory documents [7], and definitions of quality *class implemented in Korea:*

- Safety related components (Quality Class „Q“).
- Non-safety related components the failure of which may affect safety functions (Quality Class „A“).
- Other components.

The current physical condition and level of degradation of the SSCs are evaluated by means of referring to the design and manufacturing data, taking into consideration the data from testing, operation and maintenance, in accordance with the applicable standards.

The ageing management review produces analyses of whether the selected properties degradation mechanisms (ageing mechanisms) can affect SSC. These mechanisms are evaluated as follows: 1) It is determined if the ageing mechanism found for a given item forms part of the 17 mechanisms as specified in ASME Boiler and Pressure Vessel Code [9], 2) each ageing mechanism is identified, 3) the frequency and conditions of the occurrence of each ageing mechanism get identified, 4) determination is made of the type of mechanism(s) applicable to the examined component, 5) consideration is given to the availability and applicability of any operational experience.

j) IAEA Documents of the Ageing of NPP Equipment

The document IGALL Ageing Management of Nuclear Power Plants [10] provides guidelines on the potential content of an integrated ageing management program, as well as on the assessment of the ageing management program effectiveness. The NPP self-assessment of the ageing management measures shall include, as follows: 1) implementation of all in-plant measures for safety assessment, such as PSA periodic conduct, 2) conduct of external oversight - on behalf of the regulatory authority, as well as on international level (SALTO review missions of the IAEA), 3) comparing, on a periodic basis, the ageing management activities against those implemented on other NPPs (benchmarking process). It is assumed that the ageing mechanisms of the same type of equipment are the same on the different NPPs. However, an ageing effect may be manifested on one NPP, and not manifested on another one, or occur at a later stage of the operation of the particular equipment. In view of this, benchmarking against the practices of other NPPs assists in the prevention of ageing.

IGALL Ageing Management of Nuclear Power Plants [10] contains tables covering all types of materials on an NPP, all types of components, intrinsic degradation mechanisms and ageing effects.

The unified procedure Nulife, or Verlife [11] is a technical document (TechDoc) of the IAEA and it provides a methodology for: 1) assessment of the residual lifetime and integrity of components and piping of NPPs with WWER type of reactors in the course of their operation and in terms of defects caused by ductile and non-ductile fracture, fatigue and mechanical corrosion damages as a result of their operation, 2) assessment of the indications found during in-service inspection (ISI) of components and pipes, 3) preparation for reports from the periodic safety review during an NPP operation, in the part regarding the residual lifetime of equipment, 4) management of modifications of NPP equipment residual life.

III. Ageing Effects Study Methodology

Technical disciplines have been emerging based on requirements for failure and defect prevention and ageing management of mechanical and electrical system for plant life extension [4].

Failures and defects of equipment and pipelines occur when a limit condition has been reached. Limit conditions are attained in the following circumstances: 1) upon reaching of unacceptable residual changes of form due to plastic deformations, corrosion, mechanical or erosion wear, 2) upon the emergence and growth of discontinuities, 3) when the service life characteristics have reached their ultimate limit values, for example the acceptable number of load cycles.

The approach to ageing effects study shall satisfy the following main requirements:

- Protect the equipment from ageing;
- Monitor the consequences of ageing;
- Compensate the consequences of ageing;
- Improve the equipment control programs in the light of new knowledge accumulated including the programs for surveillance specimens' analysis.
- Effectiveness assessment of the testing methods and the programs.

a) Preparations: Data Acquisition

A thorough and extensive data acquisition is effected through review and analysis of the design and manufacturing documentation of each component, resulting in systematization of: 1) datasheet and design data about the facilities, 2) design changes and modernizations undertaken, 3) provisions of the normative documents, 4) operational history and testing data, 5) maintenance documentation, 6) strength analyses data, 7) data about compatibility with other components and systems, 8) results from in situ inspections (control), 9) data on the implemented operating modes, hours, number of load cycles, hydraulic tests, etc.

b) Strength Analyses

The performance of strength analyses is a mandatory part of the ageing management process [12]. All the relevant information on structural materials, geometry and design characteristics, the rest of the data from the design documentation and the components' datasheets serve as input data for the strength analyses. The cyclic fatigue effects, caused by the operational fluid need to be considered in the calculations. The current operational modes, all data about defects and non-conformances regarding the design parameters also need to be taken into account in the strength analyses. The average loads spectrum over the past 10 years of the NPP operation shall be used as a model for the future annual load. The calculations may also consider the rest of the loads. Based on the results of the strength analyses, it has been found that in the most stressed areas the metal can potentially be exposed to the highest level of ageing resulting in degradation of physical-mechanical properties, due to ageing factors such as thermal deformation and low-cycle fatigue. Occurrence of a crack may be expected in the zones of highest stress (load). Therefore, in those areas where the strength analyses indicate a potential for failure, special emphasis is placed on testing and non-destructive testing, for example, in the places of welded joints.

c) Selection of Sample Components

Ageing affects all the SSCs of a nuclear power plant. Naturally, it is not possible to subject to systematic survey for ageing effects all their thousands of components. Screening of the components due for a more extensive analysis of ageing is affected on the grounds of various factors, e.g.:

- The time in which they have been in operation.
- Number of the strength cycles.
- Conditions of operation, especially those conditions that are most relevant to the crack formation.
- Which components can be renovated through welding.

Components are allocated in groups on the basis of similarity signs. These signs may differ, but most frequently components are grouped by functional identity (e.g., the steam generators group). Other type of grouping may be founded on the results from testing, e.g., a group of components with defects that exceed certain size.

From the group, a component is selected because it is in the most unfavorable position in terms of ageing: for example, it has the worst physical condition, or it is the hardest to accessible for control purposes, or it has been subjected for the longest time to the aggressive influence of environment. From the entire group of components, one sample component can be selected to be used for an in-depth analysis of the ageing trend. After conducting these analyses, the results can be applied to the other components in the group.

After a sample component has been selected and its condition analyzed, it is assessed whether there is a need to expand the scope of inspections and monitoring, carried out up to that point, so as to cover the entire group of components. In the event of obtaining satisfactory results for a typical component, it is not necessary to extend the scope of the inspection. While if the results of the control (testing) are not satisfactory according to one or more criteria applied, then an increase in the scope of the ageing control may be recommended.

For each component, data is collected. The data collection for each component is systematically supplemented with results from regular non-destructive and other testing, component maintenance data, and information on high stress potential areas.

d) Regular and Extraordinary (Additional) Studies of Characteristics of the Mechanical Equipment

The regular studies due for each component have been described in the technical specifications for the operation of the nuclear power unit.

Additional measurements include, as follows: 1) precise measurement of the mechanical properties by means of a kinetic penetration method (kinetic hardness method), 2) ultrasonic testing of the welds integrity by means of the phased array technique, 3) on-line measurement of the decreasing wall thickness of metal facilities using combined electromagnetic-acoustic methods for selected carbon steels of pipelines subject to erosion-corrosion. This method enables 3-D scanning of the object, in order to detect cracks and wear, and permits the identifying and localization of the area of maximum metal wear.

e) Evaluation of the Adequacy of Ageing Management Activities

Ageing management activities include testing, monitoring, control, feedback and operational experience implementation, etc. These measures are apparently sufficient if the component is in good condition. On some NPPs, it has been established that for some components, for which control/monitoring is not required as per the unit's technical specifications, no tests have been conducted at all during the years of operation. This fact points to serious gaps in the maintenance and repair system, incompatible with the management of ageing processes:

1) equipment has been found not covered by the maintenance and repair measures (polar crane and refueling machine, RPV supports), 2) equipment that is on the borderline between two systems and has not been included in the scope of the maintenance and repair programs, 3) no regular periodic measurements have been made of the mechanical properties (strength, hardness) in areas with potential for failure.

In such cases, additional examinations of the mechanical properties of the metal are prescribed and carried out, in addition to the regular surveys, for example, a hardness testing is prescribed. The adequacy of the maintenance and repair measures is evaluated in terms of the activities described above.

f) Identifying the Degradation Mechanisms of the Mechanical Properties

The mechanisms of mechanical properties degradation are identified for each commodity group [10,13]. The ageing effects attributable to each mechanism are determined. Determination is also made of the ageing indicators through which the effects are manifested. The testing and diagnostic methods are defined by means of which the ageing indicators are monitored. These methods get described in ageing management programs for each commodity group.

g) Evaluation of the Effectiveness of Ageing Management Measures

The evaluation of the effectiveness of ageing management measures shall take place on a regular basis. The information items listed below serve as input data for evaluations [14, 15]

- The component condition, including the defects manifested in the facilities.
- The degradation mechanisms, i.e., those already defined and the potential ones.
- Whether the ageing effects are typical (characteristic) of these mechanisms.
- Whether the ageing indicators have been correctly identified.
- Whether the testing methods (control and monitoring) are sufficiently sensitive to capture the changes in the ageing indicators.
- Whether the periodicity of testing is adequate. If discontinuities have been found, the interval between inspections has to be shortened.
- Whether the scope of the inspected equipment is adequate.
- Let's take a closer view of the process of ageing of materials.

IV. Ageing of Materials and Degradation of Mechanical Properties

Ageing of materials stands for the change in their mechanical, physical and chemical properties, due to thermodynamic imbalance of the initial condition, and gradually bringing the structure to equilibrium in the presence of sufficient diffusive mobility of the atoms. Investigations of the ageing processes during NPP operation comprises activities such as

- Development of methodologies and instruments to diagnose the parameters of NPP in-service equipment.
- Assessment of the ageing effects on the operability of equipment in view of making corrections to the scope and periodicity of outages, maintenance, tests and inspections.
- Development of methodologies for express analysis of failures, damages and defects of components of equipment, and introducing those methodologies in the operational practice.
- Establishing an NPP information system (a database of knowledge and expert system).

a) Corrosion

Corrosion is the process of metal failure as a result of chemical or electrochemical interactions of metal with the surrounding environment [16]. The cause of corrosion is the thermo-dynamic instability of the system, composed of the metal and components of the environment. The capability of metals and alloys to resist corrosion impact of the environment is contingent on the rate of corrosion under the given conditions. The following serve as quantitative indicators of the rate of corrosion

- The time until the occurrence of corrosion outbreaks.
- The number of corrosion outbreaks for a given time period.
- The metal thickness decreases per time unit.
- The change of metal mass per surface unit and time unit.
- The change of any indicator of mechanical properties such as strength, plasticity, electrical resistance, etc.

b) Erosion

Erosion of the walls of equipment is caused by particles of various origin such as particles of metal corrosion products, sand, silicates, water drops, etc. The erosion process evolves through brittle or plastic fracture depending on the temperature.

1. Under normal temperature conditions in the plastic metals, erosion dissociation of metal occurs as results of plastic deformation on the surface. With brittle materials, erosion takes place through surface degradation in the form of cracking.
2. High temperature erosion is associated with the release of composite material – metal alloy and brittle surface oxide. The oxide layer on the metal surface may modify the process mechanism depending on the layer thickness. If the oxide layer is thin, the prevalent mechanism is associated with metal creep (elastic-plastic area). Upon the oxide layer reaching a critical thickness, the dominant mechanism is that of brittle erosion fracture.

The temperature and the characteristics of the force impact of the particles are the erosion determining parameters. The speed of oxide formation is dependent on temperature and, therefore, the same applies to the oxide layer thickness within a given timeframe. The force effect of particles is characterized by the time intervals of particles impacting on a specified point on the metal surface.

c) Ageing Effects Due to Corrosion-Erosion Processes

The corrosion-erosion processes that are typical for NPPs, type WWER consist in corrosion degradation of materials, followed by erosion wear under the impact of the fluid flow rate. Factors affecting the process include: 1) fluid composition, 2) velocity and temperature, 3) the component material and geometry, 4) the active stresses, 5) the periodicity of surface moisturizing / drying. Localized corrosion affects steam generators and reactor sealing surfaces, pressurizers and emergency core cooling system (ECCS). Intergranular corrosion can be observed on reactor, steam generators, corrosion fatigue – on steam generators and pressurizers. Stress corrosion affects reactors, steam generators, pipelines of the pressurizer systems and ECCS piping.

Regarding the bends in the pipeline system: Stresses will lead to a considerable change in the metal electrode potential. Tensile stresses (tensions) shift the electrode potential to the negative side, while the compressive stresses shift it to the positive side. The stretched sections act as anodes with regard to the rest of the metal and degrade (dissolve) most intensively.

The corrosion-erosion processes decrease pipeline wall thickness. There is increased probability of pipeline rupture and leaks of coolant. The change in the geometric dimensions of the pipeline walls leads to a change of the internal stresses. The system's failure rate increases on account of material degradation. The corrosion-erosion processes are the cause for loss of tightness of the pipeline systems. Thus, the normal operating conditions are compromised. Abnormal operation of the heat exchangers occurs as a result of the rupture of heat exchanging tubes. The general radioactivity levels increase due to activation of the corrosion products.

One of the ageing indicators is the pipeline wall thickness and it is measured periodically. The corrosion rate is inspected on a periodic basis. Tests are performed to identify presence of number, type, location and growth of surface defects, pits, and blow-holes in metal, and percentage of wear of the wall thickness of heat exchanging tubes. Conduct regular ultrasonic thickness measurement testing of walls and bends. The area surround-ding the weld joints is monitored.

Monitoring is performed of the water chemistry of the fluid inside the pipeline. The water chemistry regime is analyzed and maintained. The radioactivity indicators are measured. Corrosion evaluation for presence of sludges or deposits is to be performed of the critical areas. In-service inspection of metal is performed (visual, penetrant, eddy-current and mechanical testing). To prevent intergranular corrosion, visual inspection, surveillance specimens testing, penetrant, ultrasonic and hydraulic testing are undertaken.

d) Neutron Embrittlement

The operating conditions of the reactor pressure vessels metal are characterized by intensive neutron flux under high temperature and pressure conditions [17]. Being particles of small mass and great energy, neutrons easily penetrate the crystal lattice of the reactor pressure vessel. There are two major mechanisms of the interaction between neutrons and the particles of materials:

1. The collision between neutrons and the lattice atoms causes dislocations within the crystal lattice; neutrons may either transfer their energy to atoms through elastic impacts, or serve as the source of charged particles formation. Such processes will impair the correct position of atoms within the metal crystal grid and this will lead to defects formation. In

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case of sufficiently high neutron energy, the atom initially displaced from its balanced position may be followed by a cascade of displaced atoms.

2. Radiation impact largely facilitates diffusion of the ingredient's atoms, which is another important cause for alloy embrittlement. Moreover, as results of vacancies merging in those diffusion processes, additional pores may form in the metal, which can result in noticeable changes in the shape of the structure.

The density of radiation defects depends on the type of radiation, its parameters and the nuclear-physical characteristics of the material. The spot defects that occur – vacancies, internodal atoms, embedded atoms at sufficiently high temperature can recombine, migrate to body or surface directed leakages (dislocations, grain boundaries) form radiation stacking faults in the shape of pores and dislocation nodes. The irradiation of metal with fast neutrons results in microscopic areas of structural damages, and with high concentration of spot defects. Due to irradiation, the creep (yield) stress limit of steel may grow up to twice fold, while the strength limit increases to a lesser degree – the two limits come closer and metals harden while also losing plasticity. Current knowledge of radiation degradation assumes that the occurring defects may lead to material hardening either directly via interaction with the dislocations, or indirectly – through the changing kinetics of metallurgical reactions leading to phase drop. These effects harden the material and are dependent on neutron fluence density. The main effect of radiation degradation of metals consists in the highly limited number of active slip planes, and increased number of dislocations moving across the slip planes. This highly localized movement affects the process of local degradation in the peak of the crack. Determining the transition from elastic to brittle state or the evaluation of the shift of the brittleness critical temperature ΔT_F due to the neutron fluence F, may be performed through experimental testing of surveillance specimens, or it can be assessed numerically through the neutron fluence F. Neutron embrittlement is expressed in radiation brittleness temperature ΔT_K shifting in the direction of higher temperature values. Numerical assessment of neutron embrittlement of the reactor vessel metal is carried out using norms and standards of the country manufacturing the reactor equipment.

Due to the neutron diffusion, near the peak of the crack a circle section of embrittled metal forms, as is shown on "Figure 1". The embrittling action of metal neutrons is dependent on their density of distribution [17].

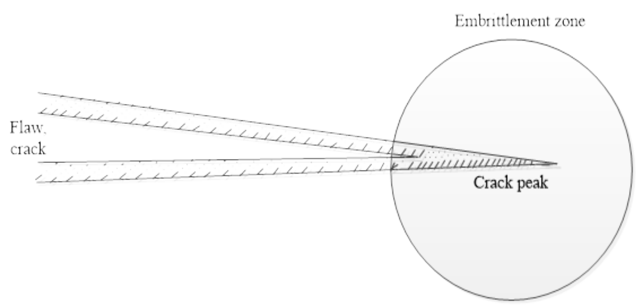
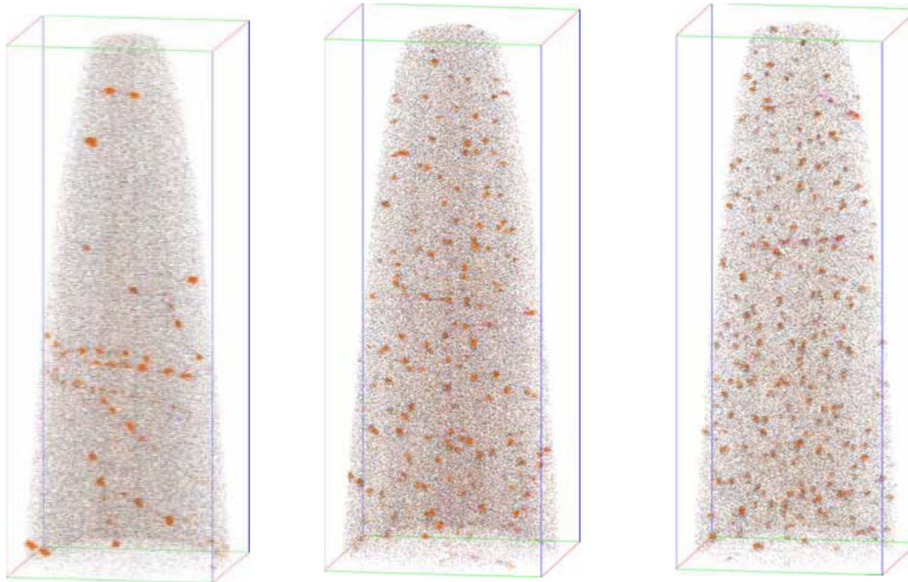


Figure 1: Material Embrittlement Around the Crack Peak

e) Effects of the Chemical Composition of Steels on the Embrittlement

The steels used for NPP's equipment are of ferrite-perlite type. The elevated levels of the elements nickel Ni and manganese Mg in reactor steel grades enhance embrittlement due to the formation of nickel-manganese-silicon Ni-Mn-Si clusters (dislocation nodes). "Figure 2" shows photos of microscope examination of samples with various weigh percentage of Ni, subjected to neutron fluence irradiation [18].



0.02 %Ni 0.82 %Ni 1.59 %Ni

Figure 2: Formation of Dislocations in Samples of Varying Weght Percentage of Ni (0.22 Cu – xNi - 1.6 Mn) at Temperature 290- 320 ºC

During irradiation the structure of materials containing copper Cu changes and Cu-enriched clusters form. The Cu-nucleus stays in the middle of the formation, while theelements nickel Ni, manganese Mn, silicon Si accumulate in the outlying sections.

These formations disrupt the correct structure of the crystal lattice. Under the impact of the operating temperature of 320 ºC, higher phosphorus content will result in thermal brittleness of metal following a mechanism based on the phosphorus segregation at the interphase boundaries and the grain boundaries. Radiation embrittlement is determined by the formation of dislocation nodes. The occurrence of these defects results in: 1) facilitating the emergence of cracks and development of micro crack on account of the active stresses, 2) additional micro stresses begin to act in the grain bodies, 3) increased probability of formation of dislocation aggregates at the barriers where micro cracks form. The neutron embrittlement mechanism is associated with the segregation of phosphorus at the inter-phase boundaries of the carbide matrix and at the grain boundaries, as a result of which their strength diminishes.

f) Thermal Ageing

In NPP facilities in operation undergo the impact of high temperature values. These working medium factors may cause thermal ageing of the base metal and weld metal in terms of alteration of their mechanical characteristics [19]. Thermal ageing is associated with displacement of atoms in the lattice of the crystalline structure; it is mainly dependent on temperature and the time period over which the metal has been exposed to its effects.

Regarding the reactor vessel materials, neutron fluence causes both thermal ageing and radiation ageing of the metal. The thermal ageing mechanism has been determined by the carbide's formation process. In the course of thermal treatment, carbon bonds in stable carbides do not change under the operating temperatures over the whole service life of the materials. Upon carbides emergence and as their amount grows, the material hardens and, as a result of this, it also becomes brittle.

The thermal ageing affects the reactor pressure vessel, barrel, core baffle, and reactor guard-tube bank. Factors affecting the process include: 1) fluence values and direction, 2) the chemical composition of materials. The elevated content of nickel Ni and manganese Mn enhance thermal embrittlement due to the formation of clusters in the radiation environment, while the content of silicon Si reduced embrittlement.

The loss of functions due to the thermal ageing is observed. There is a growing probability of brittle fracture of materials especially for the welded joints of the reactor vessel located opposite the reactor core. As a consequence of radiation swelling of metal there is growing probability of shape changing of components (core barrel); this will lead to altered load bearing capacity of the structure.

Both neutron and thermal ageing can be presented with the embrittlement function $\Delta T_K(F,t)$ – the shift of the critical brittleness temperature, which is depended from the values of neutron fluence F and time t [9,10]. The value of the shift $\Delta T_K(F,t)$ needs to be within the acceptable design limits [8]. The parameters monitored are presence of number, type, location and development of surface and internal discontinuities. The neutron flux values following each fuel cycle are recorded. In-service inspection of metal is performed (visual, penetrant, ultrasonic, eddy-current and mechanical testing). The mechanical characteristics are studied periodically, including the variation of the shift $\Delta T_K(F,t)$ of surveillance specimens from the reactor vessels. Thermal hydraulic analyses are conducted, as well strength analyses. Low-leak schemes of core refueling are used. Visual and measurements inspection of the core barrel are performed. The barrel geometry dimensions are monitored.

g) Material Fatigue

Engineering structures are subjected to pulsating (cyclic) loads [20, 21]. Under the in-fluence of cyclic loading, it is difficult to notice any progressing changes in the structure of the material. Destruction happens suddenly, without any noticeable signs of imminent occurrence. Moreover, in times of "relaxation" when stress stops acting, defects do not disappear – they accumulate and are irreversible. Fatigue can be described as a process of gradual degradation, composed of sub elements, such as: 1) the process of crack emergence, 2) crack growing to a size when its further progress is rapid and unstable. It is assumed that a crack originates as a result of the movement of dislocations, which generates thin sliding planes on the surface of the crystal lattice.

h) Ageing Effects Due to Fatigue

Cyclic fatigue affects all the main equipment pieces of the primary circuit (reactor, steam generator, main circulation pipeline, main coolant pump). Low cycle fatigue affects the secondary circuit equipment (turbine, demineralizers, separators).

Factors affecting the process include: Number N of the work cycles, amplitude of the deviation of the stress.

Loss of function of the equipment due to fatigue is observed. There is increased probability of fatigue degradation of materials. Subsequent change in the load-bearing capability of structures is expected.

The number of load cycles is monitored for the different operating modes. Monitoring is performed of the following parameters: presence of number, type, location and development of surface, below surface and internal discontinuities. The fatigue accumulation factor is periodically calculated. The load cycles are registered and monitored for the different design operating modes. A register is maintained of the number of loading cycles. Surveillance specimens are tested. In-service inspection of metal is performed (visual, penetrant, ultrasonic, eddy current testing) [22, 23]. Hydraulic testing is implemented. Fatigue analyses are performed.

i) Wear

Multiple studies have demonstrated that the process of gradual loss of functionality of components in operation can be subdivided in three stages: 1) stage of alignment, 2) normal operation stage, 3) wear, caused by facilities' normal operation.

Throughout the stage of alignment mutual changes occur in the macro- and micro-geometry of the working faces, and products of wear and oxidation are formed. The working faces wear rather intensively during this stage. Gradually, wear weakens and stabilizes to a stage of normal operation wear. Once the energy limit has been exceeded, the wear value progressively increases, the components functioning deteriorates and the need of repair arises. The following factors determine the level of wear in friction: 1) physical, chemical and mechanical properties of the surfaces subjected to friction,2) combination of materials for the working surfaces, 3) interactions of the working surfaces with the environment, 4) clean processing of the friction surfaces, 5) type of friction (dry, boundary, semi liquid, liquid), 6) values of the normal pressure and the velocity of working surfaces one against the other.

Of the large number of wear types on the working surfaces of machine parts, major importance is attached to abrasive wear in the presence of grease, because the wear products that invariably arise from the machine components friction are oxidized and turn into a sort of abrasive materials and it is rather complicated to clear lubricants from the component surface. Friction wear is one of the major contributors to the gradual loss of operability of mechanical elements. Therefore, the consideration of factors affecting the level of wear of machine parts during design and operation of mechanical systems is one of the main tasks for ensuring the reliability of the working mechanical elements in Nuclear Power Plant.

j) Ageing Effects Due to Wear

Wear affects hydraulic snubbers, sealing faces, fixing elements, internal parts of cylindrical vessels and pipelines. A photo of wear is presented on "Figure 3".

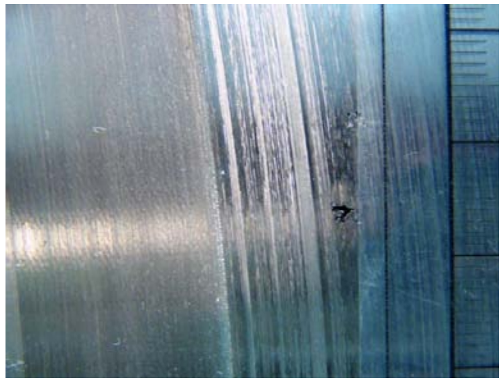


Figure 3: A Photo of Wear on Rotating Part, it Can Be Seen a Defect in Metal

Erosive wear is an issue for pipeline operation in the turbine hall. Defects of erosive nature occur at pipeline bends, and also in pipeline sections downstream of throttle and control valves. The cause for such defects is the presence of two-phase medium in the pipes and development of cavitation processes.

Plastic deformation affects steam generators, pressurizers, pipelines, of the pressurizers' system, main circulation pipelines and ECCS.

Loss of function of the equipment due to wear can be observed in a case of hydraulic snubbers' degradation. The snubbers are uncapable to performing its protective functions in case of strong vibrations, or an abrupt displacement of equipment caused by seismic loads. Regarding pins (their cylindrical part) and pin sockets – their fixing functions is impaired and it is probable that fixing will not be tight enough.

Erosion-corrosion wear processes decrease pipeline wall thickness. There is increased probability of pipeline rupture and leaks of coolant. The load-bearing capacity of the affected structures is changed.

Visual testing is performed to identify presence of number, type, location and development of any surface discontinuities. The pipeline wall thickness is measured periodically.

V. Ageing Effects of Reactor Pressure Vessels

This part of the paper reviews ageing effects of reactor pressure vessels (RPVs).

The underlying factors for selecting these items to be subjected to ageing assessment are as follows:

1) The operating life is greater than 30 years in a row.
2) Large number of the strength cycles.
3) Operating environment conditions: fluid pressure of 17.8 MPa; fluid temperature 20 ÷ 330 º C; the fluid flows at high speed.

The subject of assessment was the reactor pressure vessel metal, and the RPVs type WWER 1000 – B 320, thermal power of 3000 MW. Two power units were the subject of survey: unit "a" and unit "b". The survey period covers 30 years.

The RPV metal is subject to the following degradation mechanisms due to the operating environment factors such as neutron embrittlement, thermal ageing, embrittlement due to the presence of discontinuities, fatigue, and erosion-corrosion wear [13].

a) Study of the RPV metal ageing caused by neutron embrittlement and thermal ageing mechanisms

Subject of study are the welded joints metals of the RPVs of two type WWER reactors (provisionally referred to as "a" and "b"). The reasons justifying the choice of the specific areas for the study is that areas with degradation potential are identified in these RPV points. The welded areas have different metal structure (area of base metal, thermal impact area, and welded metal area) and the structural non uniformity is one of the main causes for the occurrence of discontinuities. The tensions active in the metal and resulting from the operating conditions are not the same for the bimetallic areas, which leads to the growth of discontinuities. The welded joints located opposite the reactor core are subject to the embrittlement action of high neutron fluence. Discontinuities were found at the places of welding; their evolution has been traced over the years of reactor operation.

The embrittlement process depends not only on the chemical composition of the alloys, but also on the values of neutron fluence, operating temperature and running hours, which can be expressed as shown below *[11, 19]:*

$$T_K = T_{K_0} + \Delta T_K(F,t) \quad (1)$$

The value added to the temperature $\Delta T_K(F,t)$ shift has two components: one of the components is due to the neutron fluence $\Delta T_K(F)$, and the other one is due to the thermal embrittlement $\Delta T_K(t)$.

$$\Delta T_K(F,t) = \Delta T_K(F) + \Delta T_K(t) + \omega \quad (2)$$

- T_{K_0} is the metal initial critical temperature that corresponds to non-irradiated condition;
- T_K is the metal critical temperature following a period of irradiation;
- $\Delta T_K(t)$ is the metal critical temperature shift, resulting from thermal ageing;
- t running hours of the reactor metal;
- $\Delta T_K(F)$ the critical temperature shift, resulting from neutron irradiation due to the neutron fluence F;
- F is the neutron fluence of neutrons whose energy exceeds 0.5 MeV, hitting the pressure vessel;
- F_0 =(10^{22} n)/m^2 is a standardised factor;
- A_F is the radiation-induced embrittlement factor;
- ω – double standard deviation of $\Delta T_K(t)$;
- ΔT_t^{inf} - is the embrittlement critical temperature shift at t=∞;
- t_{OT}, t_T, b_T – material constants;
- Ni, Mn, Cu and P represent the chemical elements concentrations in the metal composition, [weight units];
- $D = 72.10^{22}$, is a standardised factor.

$$\Delta T_K(F) = A_F(F/F_0)^m \qquad (3)$$

for base metal: m=0.8 A_F=1.45 [ºC]

for weld metal: m=0.8 A_F= $\alpha_1.\exp(\alpha_2.C_{eq.})$ [ºC]

$C_{eq.} = Ni + Mn - \alpha_3.Si$ if $Ni + Mn - \alpha_3.Si \geq 0$

or $C_{eq.} = 0$ if $Ni + Mn - \alpha_3.Si < 0$

$\alpha_1 = 0.703; \alpha_2 = 0.883; \alpha_3 = 3.885;$

$$\Delta T_K(t) = \left[\Delta T_t^{inf} + b_T.exp\left(\frac{t_t - t}{t_{OT}}\right)\right].th\left(\frac{t}{t_{OT}}\right) \qquad (4)$$

The values of the quantitiesΔT_{inf},b_t, t_{OT} for the pressure vessel metal are summarized in "Table 1".

Table 1: Values of the Quantities ΔT_{inf} , b_t, t_{OT}

Metal	Table Column Head		
	$\Delta T_{inf,}$ ºC	b_t, ºC	$t_{OT,}$hours
Base metal	18	26.2	32 700
Weld metal, Ni>1,3 %	18	10.1	23 200
Weld metal, Ni<1,3%	18	26.2	32 700

Two methods are known for determining of the critical temperature shifts $\Delta T_K(F,t)$.

The first method is a theoretical one - calculations using certain numerical models adopted in normative and methodological documents. The second method is a practical one - through analysis of surveillance specimens' material. The input data for assessments of the ageing effects are

- Datasheets with the composition of the reactor pressure vessels (Passport data).
- Data of the fluence on the RPV in the course of each fuel cycle (campaign).
- Data from NPP logbooks about the running hours in each fuel cycle.
- Data from the surveillance specimens testing.

The theoretical method for analysis of the critical temperature shift $\Delta T_K(F,t)$ is based on calculations. The values of fast neutron fluence with energy greater than 0.5 MeV, reaching the inside of the RPV wall are monitored through the neutron detector readings positioned around the reactor pressure vessel. Data sampling is performed once a year.

The practical (experimental) method for analysis of the critical temperature shift $\Delta T_K(F,t)$ is based on the results from surveillance specimens impact strength tests.

Calculations were made of the embrittlement critical temperature $\Delta T_K(F,t)$ on two RPVs with WWER-1000 reactors (referred to as "a" and "b").

The critical temperature shift $\Delta T_K(F)$, caused by the neutron fluence on base metal and weld metal is shown on "*Figure 4*".

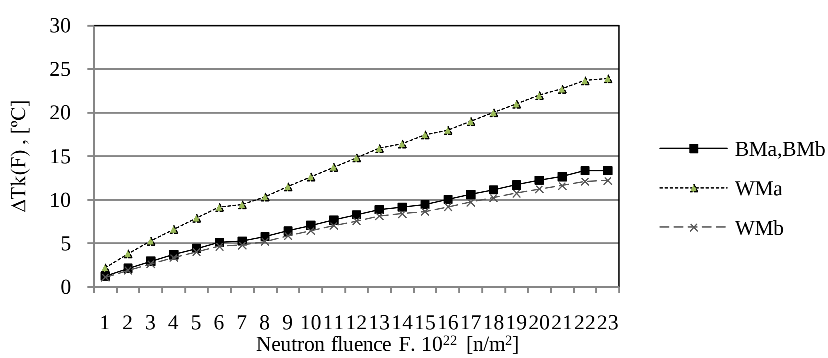


Figure 4: Function $\Delta T_K(F)$ for Base Metal BM and Weld Metal WM of the RPVs, units "a", "b"

The critical temperature shift values $\Delta T_K(F)$ grow proportionately to the increase of the fluence F values, both in the base, and the weld metal. The $\Delta T_K(F)$ curves for base metal (BMa and BMb) coincide because A_F does not depend on the chemical composition of the base metal. Difference can be observed in the neutron embrittlement rate of weld metal (WMa and Wmb); greater embrittlement rate was found for WMa. Regarding RPVb, the curves $\Delta T_K(F)$for base metal, BMb, and weld metal, WMb, almost tally.

The critical temperature shift resulting from thermal ageing $\Delta T_K(t)$ of base metal and welded metal (BMa, BMb, WMa, WMb), is shown in *"Figure 5"*.

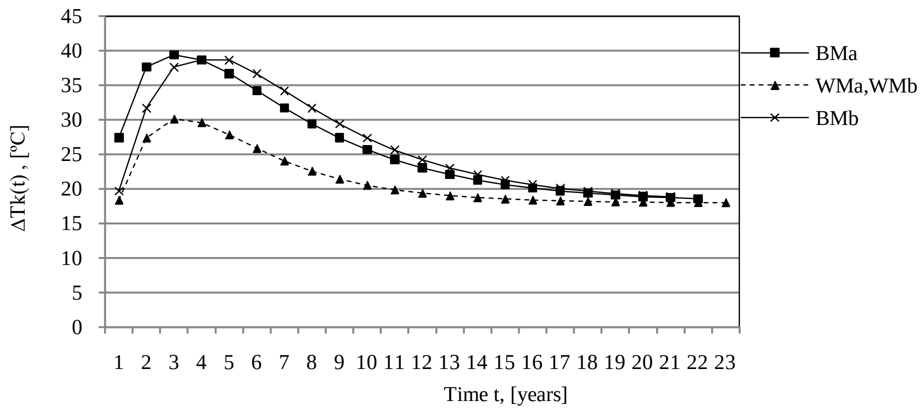


Figure 5: $\Delta T_K(t)$function of the Time t for base metal and weld metal of the reactor pressure vessels of units "a" and "b"

The curves' trend (behavior of the curves) for the thermically induced part $\Delta T_K(t)$ for base metal (BMa, BMb) anticipates the trend of the curves for weld metal (WMa, WMb). A peak can be observed for the thermal embrittlement values over a period of 2-5 years, following which the thermal embrittlement drops sharply. After the first 10-11 years of operation, the function $\Delta T_K(t)$ has almost unchangeable value, and this trend is preserved over the further operating period of the metal, both welded and base metal.

The sum of the critical temperature shifts caused by neutron and thermal ageing is:

$$\Delta T_K(F,t) = \Delta T_K(F) + T_K(t) \qquad (5)$$

The function $\Delta T_K(F,t)$ for base metal and weld metal is shown in *"Figure 6"*.

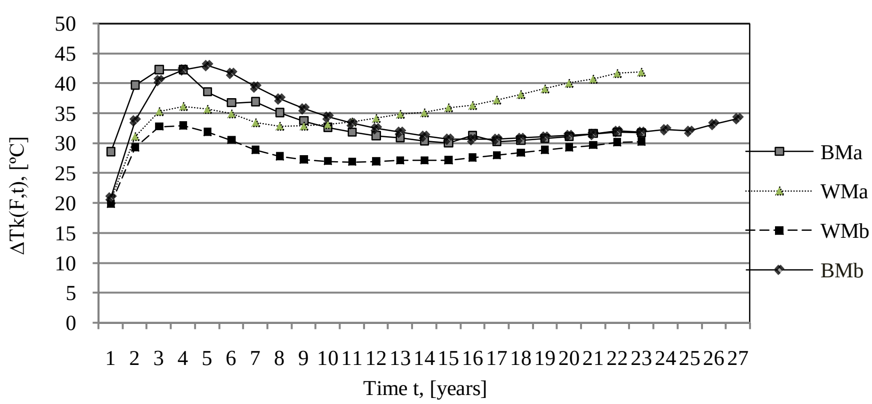


Figure 6: Embrittlement (Neutron and Thermal) for base Metal BM and Weld Metal WM The $T_K(F,t)$ Function of T time

The thermally induced embrittlement is dominant in the first 10 years of an NPP operation, after which the neutron embrittlement is prevalent. In the beginning of NPP operation the embrittlement rate of base metal BMa, BMb prevails over that of the welded metal WMa, WMb. This is followed by process reversal, i.e., prevalence of weld metal embrittlement.

A comparative analysis was conducted of the critical temperature shift values $T_K(F,t)$. Comparison was made between 1) $T_K(F,t)$ as calculated with the fluence value of the neutron detectors, and 2) $T_K(F,t)$ obtained on the basis of experimental data from the surveillance specimens (SS). The results are demonstrated on "*Figure 7*", a) base metal BM and b) weld metal WM.

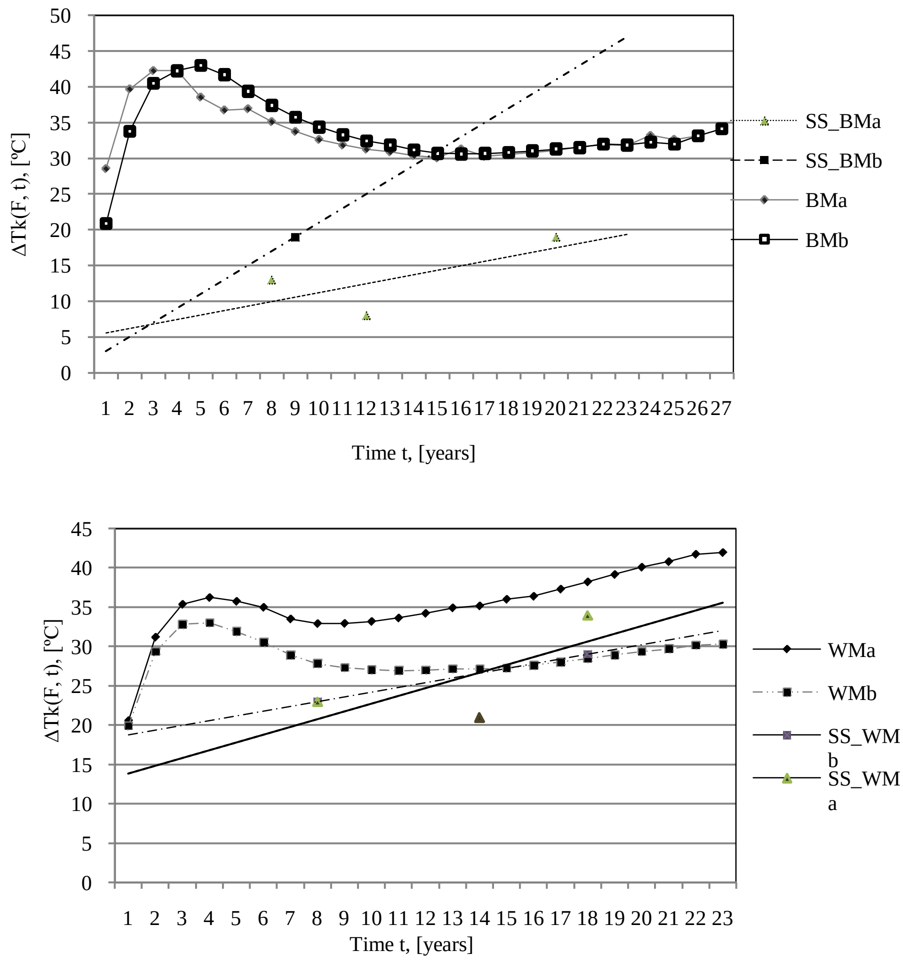


Figure 7: Function $T_K(F,t)$ of Time t for a) Base Metal BM (above) and b) Weld Metal WM. Averaged Line based on the Experimental Data from the Surveillance Specimens for a) Base Metal BM and b) Weld Metal WM

For base metal – the calculated results are higher than the experimental ones. The $T_K(F,t)$ function trend exceeds the values of the experimentally obtained data from the surveillance specimens of unit "a" base metal BMa, contrary to the case with base metal BMb.

For weld metal WMa, the trend curve $T_K(F,t)$, based on the calculations is high and quickly grows proportionally to the operating time (running hours) increase. The trend curve $T_K(F,t)$ for WMb (almost) coincides with the averaged line based on the experimental data.

The RPV metal resistance to neutron and thermal impacts is evaluated by means of the values of $T_K(F,t)$ - cold embrittlement critical temperature. With the increase of the neutron fluence value F and of the accumulated running hours, t, the values of $T_K(F,t)$ become higher. The values of $T_K(F,t)$ shall be regularly compared against the normative and the design specifications. This a main requirement of the technical specifications for safe operation of the reactor equipment. With $T_K(F,t) <$ T_{margin} (margin value), resistance of the reactor pressure vessel metal to neutron and thermal impacts has been achieved.

1) The calculated and the experimentally obtained values of $T_K(F,t)$ show that the critical embrittlement temperature shift is less than T_{margin} =57 ºC. Therefore, the requirement for resistance of the RPV metal to neutron and thermal impacts has been satisfied for units "a" and "b".
2) The curve $T_K(F,t)$ trend for welded metal with higher content of Ni exhibits the greatest dynamic. It can be concluded that these welded joints (unit "a") are the most critical element of the reactor. This inference is confirmed by the match between the calculated and the experimentally obtained data for $T_K(F,t)$.
3) Regarding base metal, a good match was obtained between the calculated data for units "a" and "b". The experimental data from the surveillance specimens testing demonstrated lower values for the lifetime characteristics $T_K(F,t)$.

b) Study of the RPV ageing metal due to corrosion-erosion wear

The RPV metal, both on the inside and on the outside surfaces can be tested (controlled) through scanning using a remote system for visual inspection. The periodicity of this activity is once in 4 years, as specified in the technical specifications (for operation of the nuclear power unit). If needed, this period can be shorter. The visual inspection method enables detecting and diagnosing surface discontinuities on the RPV inner surface. The controlled parameters are: presence or absence of discontinuities, their type, size and location [23].

To examine metal for corrosion-erosion (ageing) wear, remotely operated visual inspection is implemented. An underwater camera system is used to examine the RPV; A special software serves for storing data on the location of indications, sizing, comparing with previous data.

The input data for the studies are the parameters of discontinuities found on the inner surface of the RPV and include, as follows: 1) type of discontinuities as classified according to a standard, 2) discontinuities' location and coordinates in the metal,3) size of discontinuities, 4) orientation of the discontinuities.

The data of the discontinuities found on the RPV surface were entered in a data basis and systematized. Following 15-17 years from the first start-up of a reactor unit, the first discontinuities in the metal structure (that may actually be detected by inspection methods) can be observed on the inner surface of the reactor pressure vessel. With the progress of the unit's operating course, local merges of discontinuities can be observed. Corrosion-erosion foci are formed, concentrated in the fretting area of the strengthening nodes of the reactor internals, as is shown on *"Figure 8"*. Single surface defects are observable; the defect parameters get determined.

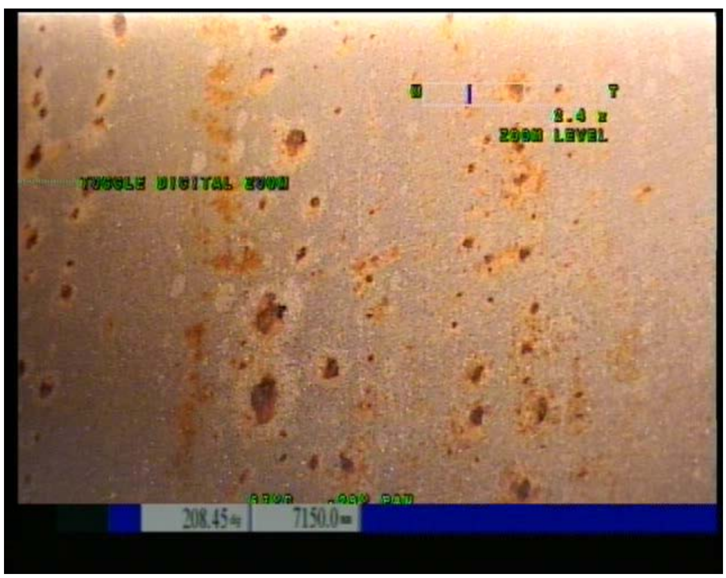


Figure 8: Discontinuities on the Inner Surface of the Reactor Pressure Vessel

The corrosion rate is one of the ageing effect indicators. The corrosion rate monitored indicators were:

- Beginning of the occurrence of corrosion outbreaks; The data on this indicator are decisive for the start of monitoring of the area.
- Changes in the size of the discontinuities monitored.
- Occurrence of new defects.

The periodicity of this inspection is specified in the technical specifications for operation of the nuclear power unit. Usually, it is once in 4 years. However, each NPP may alter it at its own discretion.

The respective parameters are identified for each defect and each group of defects. Each assessment of the parameters is followed by an analysis of the acceptability of the defects in terms of the normative requirements [23, 24]. The analytical part of the activity can offer recommendations of the future operation of the reactor equipment. Normally, these recommendations regard, as follows:

- Mechanical activities - the reactor internals shall be positioned in a way so as to prevent mechanical scratching, scuffing, denting, etc.
- The water chemistry shall be more benign to the surfaces.

c) Study of RPV Metal Embrittlement Resulting from Occurrence of a Discontinuity

The metal on the inside of the reactor pressure vessel shall be tested (controlled) once every four years (as required by normative regulations). In case defects are present or indications of defects, it is recommended that this interval be shorter. Visual inspection, penetrant testing and UT are the control methods usually applied by means of remotely controlled scanning technical tools. Non-destructive examination methods enable finding any discontinuities (defects, cracks) and studying their parameters, i.e., location, type, size, orientation.

At the places where discontinuities have been found studies are performed to identify the environmental load factors, what their values are, and whether they change with the varying design operational modes of the reactor unit. The operating conditions (for the inner surface metal) are characterized by intensive neutron flux with neutron energy exceeding 1.5 MeV; high pressure values (up to 17.5 MPa; and high temperatures of the primary circuit fluid (323°C).

Evaluations are conducted on the impact of the loads on the evolution of the defects. The discontinuities are studied by the visual inspection and ultrasonic testing, while the studied parameters are location, type and size (area). The input data of this study cover data of the defects and of the loads in effect:

- The defects indications data include: location, type, size (a, c), distance b from the internal surface of the reactor pressure vessel. The data for the defects and defect indications result from applying the non-destructive examination methods.
- Data of the neutron fluence are collected on an annual basis by monitoring the readings of the neutron detectors (reactor internal ones). Another data source are surveillance specimens that are withdrawn from the RPV and tested according to a dedicated program.
- Data of the active stresses can be obtained from the RPV datasheet and/or strength analyses of the manufacturer (conducted on unit "a").
- The load factors in the zone where defects occurred can be obtained, as follows:
- From the readings of neutron fluence detectors for the inner surface of the RPV;
- The active stresses values are obtained from the strength analyses (calculations) and equipment datasheets.

A graphical presentation method is implemented to demonstrate the neutron fluence distribution on the inner surface of the RPV metal. A coordinate system is used. Along the "x" axis the coordinates of the RPV inner surface are marked (x=0 indicates a location on the innermost layers of the reactor); the fluence values are shown on the "y" axis. The graphic representation method visualizes the fluence distribution along the thickness of the reactor wall.

Using a graphic method, the distribution of circular stresses is shown as depending on the distance "X" from the border of the deposit weld metal with the base metal of the RPV inner surface. Similarly, a graphic method is used to demonstrate the distribution of thermal stresses as dependent on the distance X from the border of the deposit weld metal with the base metal.

Selection of defects means the parameters of all the identified discontinuities are reviewed. An assessment is made to decide which of them are located in zones with a degradation potential. Large size defects present particular danger. The discontinuities located close to the inner surface of the RPV are considered to be subject to the comprehensive impact of the working environment loads inside the pressure vessel, i.e., high values for the neutron fluence and thermohydraulic loads. The discontinuities that have an opening to the RPV inner surface present a hazard for occurrence of intracrystalline (intergranular) corrosion, stress corrosion, etc. Of great significance is the orientation of the discontinuity with regard to the direction of the active loads; the most dangerous are the type A stresses (crack resistance).

Several of the "most dangerous" discontinuities are selected and calculations are made about them. For each of the selected discontinuity calculations are made to obtain: 1) the values of the stress intensity factor, and 2) the critical values of the stress intensity factor.

Brittle fracture toughness is ensured if the following condition is met with regard to the discontinuity found [19]:

$$K_I \leq [K_I]_i \quad (6)$$

$$K_I = Y.\sigma_k.\sqrt{a} \quad (7)$$

where σ stands for the load, and Y is a coefficient related to the discontinuity shape, a is the small semi-axis of the discontinuity, as is shown on the *"Figure 9".*

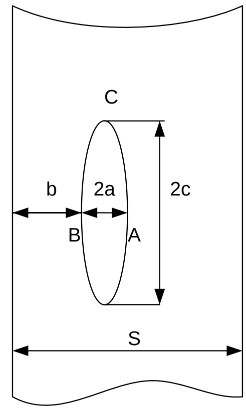


Figure 9: A diagram of a below-surface discontinuity; a - small semi-axis.

For a below-surface discontinuity in point A, of "Figure 9":

$$Y = \frac{1.79 - 0.66.\left(\frac{a}{c}\right)}{\left[1 - \beta^{1.8}.\left(1 - 0.4.\frac{a}{c} - 0.8.\gamma^{0.4}\right)\right]^{0.54}}$$

$$\beta = \frac{a}{a+b};\quad \gamma = 0.5 - \frac{a+b}{S};\quad b + a \le \frac{S}{2}$$

$$\sigma_k = \frac{3\sigma_A + \sigma_B}{4} + \frac{(\sigma_A - \sigma_B).\left(\frac{a}{c}\right)}{12}$$

For a below-surface discontinuity in point B, of "Figure 9":

$$Y = \frac{1.79 - 0.66.\left(\frac{a}{c}\right)}{\left[1 - \beta^{1.8}.\left(1 - 0.4.\frac{a}{c} - \gamma^{2}\right)\right]^{0.54}}$$

$$\sigma_k = \frac{\sigma_A + 3.\sigma_B}{4} + \frac{(\sigma_A - \sigma_B).\left(\frac{a}{c}\right)}{12}$$

For a surface discontinuity in point A, of "Figure 9":

$$Y = \frac{2 - 0.82.\left(\frac{a}{c}\right)}{\left[1 - \left(0.89 - 0.57.\sqrt{\frac{a}{c}}\right)^{3}.\left(\frac{a}{S}\right)^{1.5}\right]^{3.25}}$$

$$\sigma_k = 0.61.\sigma_A + 0.39.\sigma_B + \left[0.11.\frac{a}{c} - 0.28.\frac{a}{S}.\left(1 - \sqrt{\frac{a}{c}}\right)\right].(\sigma_A - \sigma_B)$$

For a surface discontinuity in point B, of "**Figure 9**":

$$Y = \frac{\left[2 - 0.82.\left(\frac{a}{c}\right)\right].\left[1.1 + 0.35.\left(\frac{a}{S}\right)^{2}.\sqrt{\frac{a}{c}}\right]}{\left[1 - \left(0.89 - 0.57.\sqrt{\frac{a}{c}}\right)^{3}.\left(\frac{a}{S}\right)^{1.5}\right]^{3.25}}$$

$$\sigma_k = 0.18.\sigma_A + 0.82.\sigma_B$$

For welded joints:

$[K_I] = 25 + 27.\exp 0.0235.(T - T_K)$ in hydraulic tests mode (8)

$[K_I] = 35 + 53.\exp 0.0217.(T - T_K)$ in accident conditions (9)

The study was conducted over the years 1993 - 2014.

Remotely operated equipment for visual inspection and ultrasonic testing scanning type of equipment that permits sequential sounding of all parts of the reactor pressure vessel (object of control). The sounding (a signal is input in the metal and then the reflected signal is registered) is remotely operated. Software instrumentation is employed to register the results. All identified images for defect indications are stored in the memory, their size is taken as well as coordinates. To complete this activity a UT system, type P-scan, for the RPV inner surface is used together with a type Tomoscan system.

The results are obtained using the following algorithm:

1) Regular, periodic non-destructive examination of the reactor pressure vessel is conducted implementing inspection methods, i.e., remote visual inspection and ultrasonic testing). This NDE is held once every 4 (four) years.
2) If indications of discontinuities have been found, their parameters shall be identified, i.e., length, location and size of equivalent area (UT characteristics of the indications).
3) If discontinuities have already been found during preceding NDE campaigns, the discontinuity indications' parameters are measured again.
4) A data base is established and the indications' data are input in it following each NDE of the RPV.
5) The data of the discontinuity indications are arranged by 1) size of the length, 2) area, 3) location, 4) the RPV operating period (in years). The location of the indications in the RPV metal is registered in a 3-D coordinate system - height, RPV length and depth of embedding in the metal, as read from the RPV inner surface.
6) A screening of the discontinuities is performed for the purpose of further assessments and calculations. The indications having the largest area have their location tracked in terms of the distance from the RPV inner surface. The location is an important factor as the values of the fluence and the thermohydraulic loads tend to change in the different points of the RPV.
7) A graphic method is implemented to demonstrate the neutron fluence distribution on the inner surface of the RPV metal.
8) As regards the fixed locations of the indications (critical zones), the circular stresses and temperatures are considered under the different operating modes of the reactor unit. To ensure conservatism of the calculations, the highest values are used for: 1) circular stresses, 2) temperatures under all the design modes.
9) The number of years elapsed since the start of operation of the pressure vessel are taken into account. The operating period is important for the evolution of the discontinuities - whether the thermal embrittlement or the neutron one have greater impact, insofar as these influences can be considered separately in the analyses.
10) Calculations are made of the stress intensity factors K_I for selected indications. The critical temperature shift $\Delta T_K(F,t)$ is calculated using two methods: 1) according to the strength norms [19] and 2) according to the European documents [11].
11) Calculations are made for the critical values of the stress intensity factors K_I.
12) The results obtained for the stresses intensity factors K_I are compared with the critical ones $[K_I]$, as in "Equation (6)".

A graph has been prepared demonstrating the distribution of the relative values of the neutron fluence along the depth of the RPV, as shown in *"Figure 10".*

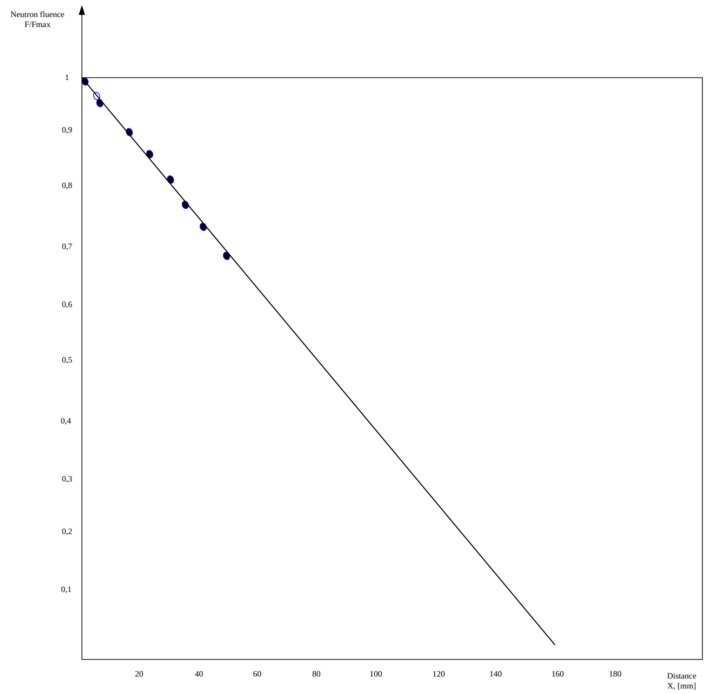


Figure 10: Distribution of the Relative Values of the Neutron Fluence F/F_{max} on the Inner Metal Surface of the Reactor Pressure Vessel

Non-destructive visual inspection and ultrasonic testing were performed. The indications parameters, such as size, location coordinates, year of size taking, were assessed. The data of a welded joint indications and the relative values of the neutron fluence F/F_{max} are shown in *"Table 2".*

Table 2: Indications of Welded joint 2 of the Reactor Pressure Vessel – Sizes, Coordinates and Neutron Flux at the Position ot the Indicates

	Size and coordinates: a) Along the weld. b) Along the reactor height. c) In depth of the weld, on the outside.					
Indication №	1	2	3	4	5	6
Size [mm]	478	39	39	150	55	27
a) [grad]	64.4	79.9	85.4	88.4	104.9	107.4
b) [mm]	274.5	276.3	277	276.7	276.8	277
	520	52	53.7	51.4	51.6	50.6
Neutron flux F/F_{max}	0.15	0.15	0.15	0.15	0.15	0.15

Indications were identified at two more welded joints of the reactor pressure vessel. To forecast the development of the discontinuity's indications in the metal, the typical transitional state of "Accident conditions - Primary circuit large leak" has been considered. Pursuant to the register of the implemented operational cycles, the large leak mode is associated with the highest amplitude values for stress-temperature fields.

"Figure 11" demonstrates the relative distribution of circular stresses as dependent on the distance X from the border of the deposit weld metal with the base metal.

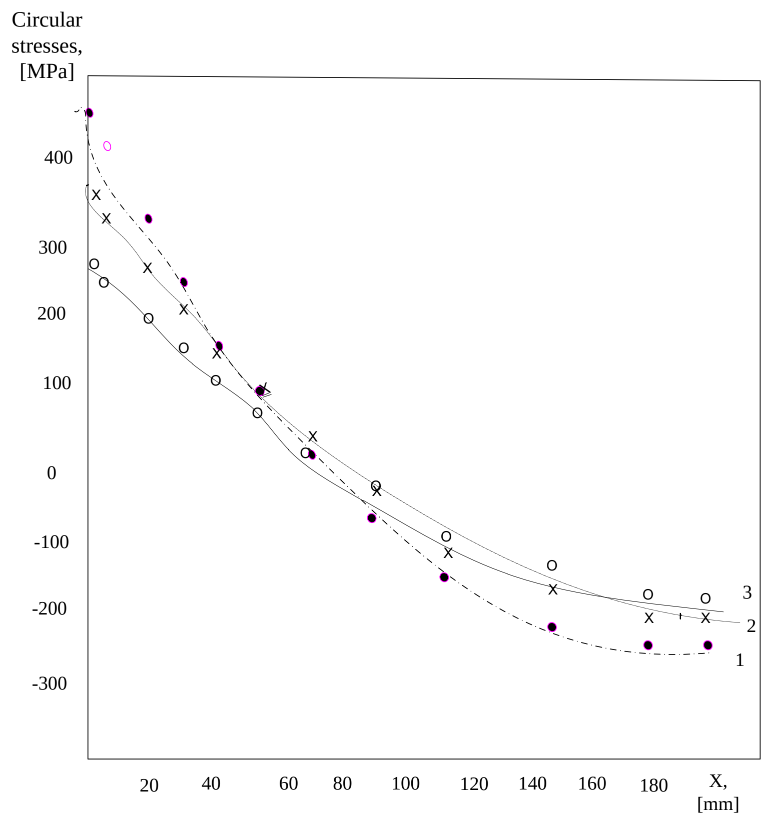


Figure 11: Relative Distribution of Circular Stresses as Dependent on the Distance X from the Border of the Deposit Weld Metal with the Base Metal. X=0 is the Position that is Closest to the Inner Surface of the RPV; the Active Stresses have Maximum values. Curve 1 – at the Moment of 0.2 hrs of the Time Interval of the Mode; Curve 2 – at 0.4 hrs; Curve 3 – at 0.6 hrs

"Figure 12" shows the temperature distribution in the RPV metal depending on the distance "X" from the border of the deposit weld metal with the base metal.

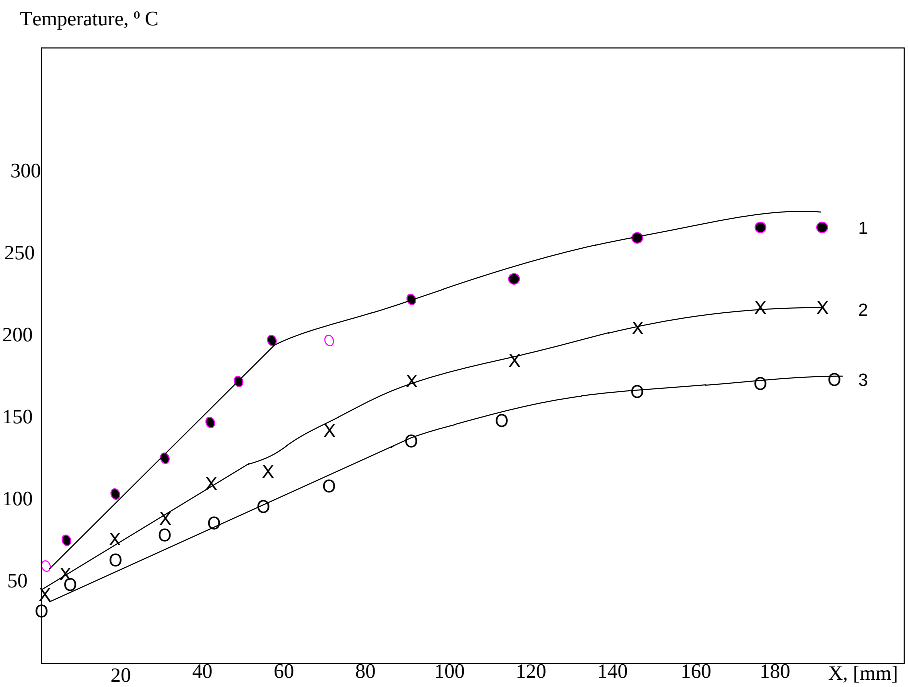


Figure 12: Temperature distribution in the pressure vessel metal as dependent on the distance X from the border of the deposit weld metal with the base metal. Primary circuit large leak mode: Curve 1 – at the moment 0.2 hrs of the time interval of the mode; curve 2 – at 0.4 hrs; curve 3 – at 0.6 hrs

The values of the circular stresses and the temperature at the locations of discontinuities are provided in "Table 3" and "Table 4".

Table 3: Stresses Values at the Locations of Discontinuities $\sigma_{\Theta BH}$ - Circular Stresses of the Base Metal Inner Surface

Weld joint/ Indication №	Distribution of circular stresses at the locations of discontinuities for the "Primary circuit large leak" mode, $\sigma_{\Theta BH}$ [MPa]		
	0,2 hrs	0.4 hrs	0.6 hrs
2 / I	-210	-170	-160
2 / II	-210	-170	-160
2 / III	-210	-170	-160
2 / IV	-210	-170	-160
2 / V	-200	-175	-160
2 / VI	-240	-190	-180
3 / I	487	350	260
3/ II	-80	-175	-150
3 / III	-110	10	-35
3 / IV	-250	-190	-185
4 / I	450	140	130
4 / II	210	250	200
4 / III	-200	-115	-120

Table 4: Temperature Values at the Locations of Discontinuities.

Weld joint/ Indication №	Distribution of temperature in the RPV metal for the "primary circuit large leak" mode, [°C]		
	0,2 hrs	0.4 hrs	0.6 hrs
2 / I	260	180	158
2 / II	260	180	158

Weld joint/ Indication №	Distribution of temperature in the RPV metal for the "primary circuit large leak" mode, [°C]		
	0,2 hrs	0.4 hrs	0.6 hrs
2 / III	260	180	158
2 / IV	260	180	158
2 / V	260	178	150
2 / VI	250	190	160
3 / I	70	55	45
3/ II	240	177	145
3 / III	210	160	130
3 / IV	250	190	167
4 / I	150	110	70
4 / II	108	65	60
4 / III	240	170	140

For the purpose of this study, calculations were made of the stress intensity factors $K_I$under accident conditions and "primary circuit large leak" mode. The stress intensity factor, a below-surface discontinuity is calculated with the "Equation (7)".

A screening was performed to select the discontinuities have to represent the worst-case scenario. Two indications were chosen of weld joint № 2 that are largest in size compared with the rest of discontinuities identified, and are located in areas where high temperature of the metal is expected in the primary circuit large leak mode. Also, an indication of welded joint № 3 was singled out as it was large in size and was located in close proximity to the inner surface of the RPV. The stress intensity factors K were calculated for selected indications. The results for the calculations of $K_I$are provided in *"Table 5".*

Table 5: The Results for the Calculations of K_I Under Emergency Condition, Primary Circuit Large Leak Mode

Weld joint/ Indication №	$\mathbf{K_I}$ in point A, circular stress, under emergency condition, primary circuit large leak mode, [MPA.$\sqrt{m}$]		
	0,2 hrs	0.4 hrs	0.6 hrs
2 / I	21.02	17.02	16.02
2 / IV	23.8	19.2	18.1
3 / I	60.21	43.27	32.14

Calculations were made of the limit values of the stress intensity factors $[K_I]$ under emergency condition, primary circuit large leak mode. "Table 6" contains the results about indication № 1 of welded joint № 3.

Table 6: The Results for the Calculations of K_I and $[K_I]$, under Emergency Condition, Primary Circuit Large Leak Mode

Weld joint/ Indication №	$\mathbf{K_I}$ in point A, circular stress, under emergency condition, primary circuit large leak mode, [MPA.$\sqrt{m}$]		
	$[K_I]$	$[\mathbf{K_I}]$ per [19]	$[K_I]$ per [11, 25]
3 / I	60.21	108	123

For Indication №1 of welded joint №3 a comparison was made between the current values of the stress factor and the limit value[]:

$$K = \{60{,}21;\ 43{,}27;\ 32{,}14\} < [] = \{108, 123\}$$

Meeting the condition of "Equation (6)" is a regulatory criterion that fracture of the weld joint will not occur as a result of brittle fracture due to the present discontinuity in case of accident conditions, with primary circuit large leak mode.

VI. Conclusions

Currently, metal ageing issues have been gaining increasing topicality as the equipment in most of the operating Nuclear Power Plants is already "aged", and although a good deal of knowledge has been accumulated on NPP components ageing, it is becoming clear that there are still a great many unexplored areas.

NPP equipment and components are subject to the continued impact of stress factors. The mechanisms of the mechanical properties' degradation of WWER reactor type metal components are corrosion, erosion, neutron and thermal ageing, fatigue and wear. These impacts induct changes in the mechanical properties of metal and, eventually, result in the component's loss of operability. The latter could compromise the NPP safety and also cause economic losses due to generation losses.

The degradation mechanisms of mechanical properties have been individually researched into a laboratory conditions, while materials in NPP are subjected to integrated impact of load factors. In general, the proposed lifetime characteristics assessment methodologies are based on the independent occurrence of processes such as corrosion, fatigue, creep and neutron embrittlement, although in reality these processes run simultaneously in various combinations [26].

The paper proposes a methodology for study of ageing effects. A case is presented of implementation of the methodology for assessment of ageing effects of reactor pressure vessels. The RPV is subject to the impact of multiple load factors.

Of all the degradation mechanisms that affect the RPV, the radiation and neutron fluence thermal impacts are the most destructive ones. Over the first decade of an NPP operation, thermal embrittlement is dominant, followed by neutron embrittlement. The nickel (Ni) content enhances the embrittlement trend which is manifested in the growing value of the embrittlement temperature shift. Greater embrittlement occurs in weld metal than in base metal.

The evaluation of the ageing effects points out that one of the greatest hazards for the integrity of the reactor pressure vessel is the presence of a defect/defects on account of them posing the possibility for brittle fracture. The following cases of RPV metal defects were studied: 1) surface defects of base metal; 2) defects of weld joints in the maximum neutron fluence areas (dominant factor); 3) defects in areas with high values of stress and temperature (dominant factor).

Based on the studies performed it can be concluded that case 2) poses the greatest hazard.

Defects in metal on account of equipment ageing occur following a long term of operation. Before extending the NPP lifetime it is required to confirm the operability of components. Equipment condition investigation is a challenge since, clearly, one cannot destroy non-replaceable equipment of an NPP in operation in order to examine its degree of degradation. Therefore, it is important to track the manifestation of ageing effects throughout all stages of NPP operation.

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Multivariate Analysis of the Historical Precipitation of Nicaragua, Costa Rica, and Honduras with the Global Historical Precipitation from Worldclim

By Victor Rogelio Tirado Picado
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Keywords: *worldclim, correlation analysis, multivariate, precipitation, hydrology.*

GJSFR-H Classification: *UDC: 551.58*

MULTIVARIATEANALYSISOFTHEHISTORICALPRECIPITATIONOFNICARAGUACOSTARICAANDHONURASWITHTHEGLOBALHISTORICALPRECIPITATIONFROMWORLDCLIM

Strictly as per the compliance and regulations of:

Multivariate Analysis of the Historical Precipitation of Nicaragua, Costa Rica, and Honduras with the Global Historical Precipitation from Worldclim

Victor Rogelio Tirado Picado

Summary- The present investigation includes the analysis of the correlation of the variable historical precipitation of the Nicaraguan airport station, the El Indio coffee plantation station, San Vito-Puntarenas in Costa Rica, and the Amapala station in Honduras versus the historical precipitation of global data from WorldClim, based on of the multivariate correlation analysis technique. The research questions are formulated in relation to the correlation of historical precipitation data at three different points in the Central American region versus the WorldClim global precipitation database, and that these can be used to perform specific hydrological analyzes at lack of them. As a result, four possible combinations were produced, where Y were the global WorldClim data, the data from the Nicaragua station, then the data from the Costa Rica station and finally the data from the Honduras station, determining R2 correlations of the order of 0.98, 0.98, 0.99 and 0.95 respectively, this goodness-of-fit correlation indicates that there is a lot of precision, demonstrating that the data from WorldClim or from another station in the Central American region can be used from the calculated coefficients to perform hydrological studies in the absence of information.

Keywords: worldclim, correlation analysis, multivariate, precipitation, hydrology.

I. Introduction

In order to be certain of the simultaneous effects of several variables, multivariate statistical methods are used to analyze the behavior of the set of different random variables. The main objective of the multivariate analysis is highly variable in relation to what we want to achieve with them, which raises the different scenarios that explain the objective of the multivariate analysis.

In this sense, there are some applications of multivariate analysis for hydrometeorological factors, such as (Soley & Alfaro, 1999) proposes multivariate analysis methods that by the year 1999, were being applied in the Geophysical Research Center in the projects of study of climatic variability, and names three methods: principal component analysis, singular value decomposition, and the canonical correlation method. (Soley & Alfaro, 1999) in their scientific publication, conclude that, despite the fact that the precipitation fields of the Pacific and the Caribbean are climatologically different, the anomalies could show similar behaviors when affected by large-scale processes.

It can be mentioned that (Entrajes, Varni, Gandini, & Usunoff, 1996) carried out a research work based on the analysis of principal components (PCA), of homogeneous regions of precipitation in the area of the Arroyo del Azul basin (6237 km2), which is located in the center of the province of Bs. As., Arg. The identification of these regions allowed researchers, among other applications, their inclusion in hydrological models of water flow (surface and groundwater), and in the agroecological regionalization of the area.

As a result (Entrajes, Varni, Gandini, & Usunoff, 1996), determined from the analysis of data from 12 stations from the period 1985-1994, two components were selected that, together, consider more than 89% of the variance. total contained in the original data. Precipitation being a continuous spatial function, and that the principal components derived from them are also continuous and, therefore, the load distribution maps express the association between the precipitation at each point in the basin and that registered at the hypothetical station. What does each principal component represent?

The main objective of this research work is to analyze the correlation of the historical precipitation variable of three stations located in Nicaragua, Costa Rica and Honduras, with the global historical precipitation data from WorlClim, implementing multivariable statistical methods to answer the following question.: Will historical precipitation data for Nicaragua, Costa Rica, and Honduras be correlated with WorldClim global historical data, and can WorldClim global historical data be used for a timely hydrological analysis in the absence of that?

II. Objectives

a) General Objective

Analyze the correlation of the historical precipitation variable of Nicaragua, Costa Rica, and

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Honduras with the global historical precipitation of WorldClim.

III. Especifics Objectives

Detail historical precipitation data for each area of interest, as well as global data.

Develop the multivariable correlation model between the precipitation data of each area of interest with the global data.

Examine the influence of global precipitation data in the studied area of interest.

IV. Methodological design

a) Kind of Investigation

The present work was designed under the methodological approach of the quantitative approach, since this is the one that best adapts to the characteristics and needs of the present investigation.

The quantitative approach uses data collection and analysis to answer research questions and test previously established hypotheses, and translates into: “the sequential and probative. Each stage precedes the next and we cannot "jump" or avoid steps. The order is rigorous, although of course, we can redefine some phase. It starts from an idea that is being delimited and, once defined, objectives and research questions are derived, the literature is reviewed and a theoretical framework or perspective is built. From the questions hypotheses are established and variables are determined; a plan is drawn up to test them (design); variables are measured in a certain context; the measurements obtained using statistical methods are analyzed, and a series of conclusions regarding the hypothesis or hypotheses are drawn”. (Sampieri, Fernández Collado, & Baptista, 2014. Page 5).

The observation technique was taken from the quantitative approach, the database information is collected and can be quantified. Data collection is done through quantitative observation, since it allows quantifying the behavior of precipitation over time.

b) Execution Time

In the development of the research work, there were three months, of which one month to obtain the precipitation data of a series from 1960 to 2021 global climate of WorldClim, one month to process the data from different sites of study interest. at the regional level, and one month to obtain and write the final report, in the period from April to June 2023.

c) Data Collection Technique and Method

By downloading high-resolution global weather-climate data of precipitation, for mapping using the WorldClim spatial model. The data is used for mapping and spatial modeling. Since the data is provided for use in research and related activities.

By obtaining precipitation data from the INETER database, from the airport station, Managua Nicaragua.

By obtaining precipitation data from the database of the National Meteorological Institute of Costa Rica.

By obtaining precipitation data from the database of the Center for Atmospheric, Oceanographic and Seismic Studies.

Microsoft Excel will be used, since it brings together the statistical applications used for this study.

i. *Primary Sources*

WorldClim Portal, Global Climate and Weather Data: Historical Climate Data, Historical Monthly Weather Data for Precipitation.

Portal of the Nicaraguan Institute of Territorial Studies, historical monthly precipitation data.

Portal of the National Meteorological Institute of Costa Rica, historical monthly precipitation data.

Portal of the Center for Atmospheric, Oceanographic and Seismic Studies of Honduras, historical monthly precipitation data.

ii. *Secundary Sources*

Scientific articles related to the use of multivariable statistical methods.

Bibliography related to multivariate statistics.

Library of the Nicaraguan Institute of Territorial Studies of Nicaragua (INETER), meteorology department.

d) Universe

Regional precipitation data for Nicaragua, Costa Rica, Honduras, and global precipitation data fromWorldClim.

e) Population

The precipitation database for the Aeropuerto station in Nicaragua, the El Indio coffee station, San Vito-Puntarenas in Costa Rica, and the Amapala station in Honduras, as well as the precipitation database for the Central American region.

f) Sample

Airport station precipitation database for the period 1958-2020 in Nicaragua, El Indio coffee station precipitation database, San Vito-Puntarenas for the period 1968-2020 in Costa Rica, Amapala precipitation database in the period of 1952-2020 in Honduras, and database of global precipitation in the period of 1960-2021 of Worlclim.

g) Inclusion Criteria

We worked with precipitation data in raster format from regional WorldClim in Central America, precipitation data measured from the Nicaraguan airport station, precipitation data measured from the El Indio coffee station, San Vito-Puntarena in Costa Rica, and precipitation data measured from the Amapala station in Honduras.

h) Exclusion Criteria

All those precipitation data that are not measured from the stations: airport in Nicaragua, El Indio coffee plantation, San Vito-Puntarena in Costa Rica, and Amapala in Honduras, and that are not studied in the 1958-2020 ranges, 1968-2020, 1952-2020 and 1960-2021 established by each station respectively.

V. Theoretical Aspects

There are many definitions of multivariate statistics, according to the complexity of the problem, there are techniques that range from the simplest to the most complex. There is no single definition, therefore, the definition in which the study carried out in this investigation is most accurately adapted will be used.

According to (García, 2021), defines multivariate statistics as different methods that study and examine the simultaneous effect of multiple variables. (García, 2021) also describes that multivariate methods are used to analyze the behavior of the set of more than one random variable.

There is a wide multivariate technique used for the analysis of multiple data, and they are available in various statistical studies, some of which will be mentioned.

a) Matrix Chart

This Matrix Graph technique, (García, 2021) states that in this technique it is used to show the pairs of X-Y graphs of a set of quantitative variables. It is an excellent technique if it is required to detect pairs of highly correlated variables, and it can also detect cases with outliers.

b) Correlation Analysis

(García, 2021), on this occasion he defines in his blog, that it is a process of correlation analysis and its objective is to summarize two or more columns of numerical data. Calculate summary statistics for each variable, as well as the correlation and covariance between the two.

c) Spider Diagram

Taking (García, 2021) as a reference, he defines this technique as a spider diagram that is also known as a radar graph, it is used to show the values of various quantitative variables depending on the situation.

Then there is the *Factorial Analysis* technique (García, 2021), he defines it as the analysis that produces a linear combination of multiple quantitative variables, these variables represent the highest percentage of variation. These types of analyzes are used to narrow the scope of the problem in order to better understand the factors that affect the variables studied.

d) Logistic Regression Analysis

(García, 2021), states that the logistic regression analysis, is also known as a selection model, is a multiple regression variable that allows predicting events and studies the influence of two types of variables on each other: dependent variables and non-dependent variables. The first is an explanatory variable, while the second is a non-explanatory variable. The first variable describes the current state of the database, and the second interprets the data through the dependency between two variables. (García, 2021) ensures that it is a technique that helps predict the choices that consumers can make when choosing alternatives.

Finally, not the last, but if one of the most important, you have the *Linear Discriminant Analysis,* (García, 2021), describes that it is a technique that was designed to help distinguish two or more sets of data based on a set of quantitative variables. This is achieved by establishing a discriminant function or linear combination of variables.

To mention a few more, there is *Correspondence Analysis, Multidimensional Scaling, and Canonical Correlation.*

The multivariate analysis technique is based on optimizing the data or simplifying the structure of the data, ordering and grouping the data, investigating the dependency relationship between variables, predictive relationship between variables, construction and testing of hypotheses. And it is from here that logistic regression analysis has been identified as the most important technique.

VI. Results

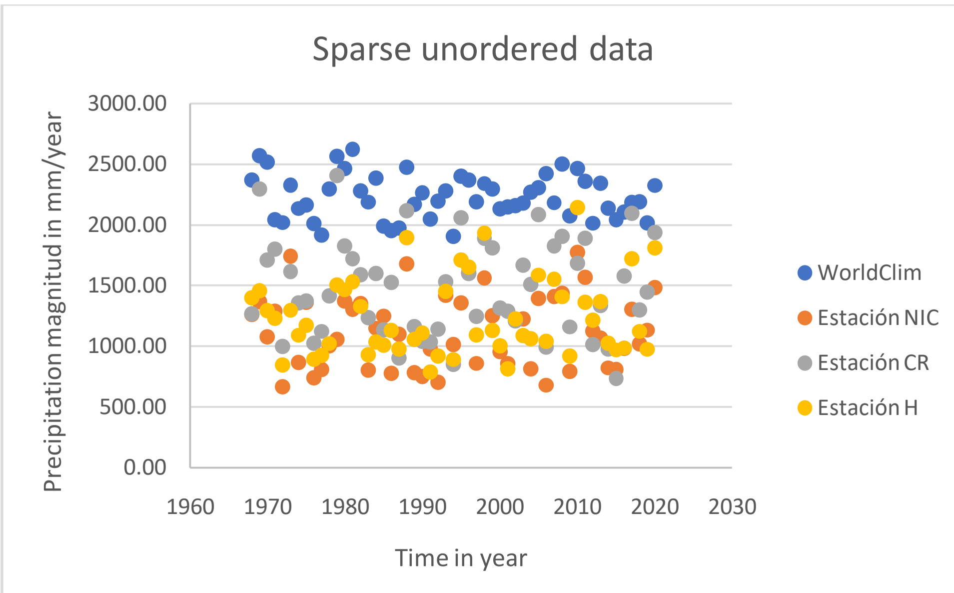
According to the preparation of the data, certain years are discriminated until measurement homogeneity is reached in the same year. In this case, the analysis is carried out from 1968 to 2020, which is where the data is complete in a homogeneous manner. See table 1:

Table 1: Cumulative, Global and Station presentation data for Nicaragua, Costa Rica and Honduras

Year	WorldClim Accumulated	Estation NIC Accumulated	EstationCR Accumulated	Estation H Accumulated
1968	2371.86	1266.60	1271.6	1401.90
1969	2571.41	1368.50	2297	1458.30
1970	2517.08	1082.00	1714.2	1294.80
1971	2043.23	1293.40	1803.3	1231.60
1972	2021.77	669.70	1000.5	847.00
1973	2327.46	1742.90	1617.6	1299.10
1974	2137.27	868.80	1358.8	1092.60
1975	2168.22	1365.00	1374.2	1175.20
1976	2013.26	744.40	1025.7	896.40
1977	1918.44	812.70	1124.4	926.60
1978	2297.52	1008.10	1417.8	1024.70
1979	2563.92	1058.70	2410.1	1507.10
1980	2466.21	1376.00	1831.1	1468.00
1981	2623.52	1306.10	1721.9	1535.10
1982	2280.63	1354.40	1590.5	1331.00
1983	2189.58	806.70	1237	933.10
1984	2385.22	1151.90	1600.8	1036.20
1985	1994.12	1251.90	1136.2	1010.10
1986	1955.51	780.20	1530.2	1132.80
1987	1975.43	1102.80	905.2	977.70
1988	2474.85	1679.60	2117.3	1898.80
1989	2171.58	785.20	1163.4	1059.40
1990	2266.09	755.80	1040.2	1111.70
1991	2052.21	980.50	1039.4	788.80
1992	2196.25	704.80	1143.5	921.40
1993	2281.27	1420.00	1533.4	1456.70
1994	1908.26	1018.90	851.9	891.80
1995	2400.96	1360.20	2061.2	1715.10
1996	2372.41	1608.60	1601.9	1655.20
1997	2193.98	862.40	1246.6	1096.40
1998	2342.17	1565.00	1891.5	1933.70
1999	2295.39	1253.90	1815.4	1130.50
2000	2133.99	957.10	1317.1	1005.10
2001	2149.15	862.00	1289.6	814.70
2002	2163.02	1224.60	1208.6	1227.80
2003	2179.96	1229.60	1672.2	1089.50
2004	2271.23	819.20	1512.5	1065.20
2005	2307.87	1395.10	2086.8	1589.10
2006	2423.60	683.30	993.5	1042.50
2007	2184.45	1411.90	1830.3	1556.00

2008	2500.90	1439.50	1907.6	1410.20
2009	2078.57	796.10	1162	921.60
2010	2466.79	1775.90	1684.6	2146.80
2011	2359.83	1569.70	1892.8	1364.80
2012	2016.52	1126.00	1017.7	1215.70
2013	2346.10	1070.40	1339.4	1369.70
2014	2138.03	825.60	980.4	1027.60
2015	2044.55	813.80	736.3	971.30
2016	2109.52	986.10	1581.2	986.90
2017	2185.27	1309.00	2096.2	1722.20
2018	2192.44	1022.90	1301.1	1124.70
2019	2021.07	1136.20	1448	976.90
2020	2326.52	1484.60	1939.4	1811.70

Source: (CENAOS, 2023), (DatosMundial, 2023), (INETER, 2023), (WorldClim, 2023)



Note: figure created from the database

Figure 1: Behavior of Precipitation Data Over Time Without Manipulation

From the data, from a series of 53 data, we continue to order them from lowest to highest and the correlation analysis technique is implemented, see Table 2.

Table 2: Sorted database

Year	WorldClim	Estation NIC	EstationCR	Estation H
	Accumulated	Accumulated	Accumulated	Accumulated
1	2021.77	806.70	736.3	986.90
2	2043.23	812.70	851.9	1005.10
3	2044.55	813.80	905.2	1010.10
4	2052.21	819.20	980.4	1024.70
5	2052.70	824.20	993.5	1027.60
6	2078.57	825.60	1000.5	1036.20
7	2083.28	862.00	1017.7	1042.50
8	2109.52	862.40	1025.7	1059.40
9	2133.99	868.80	1039.4	1062.80

10	2137.27	878.20	1040.2	1065.20
11	2138.03	957.10	1124.4	1089.50
12	2149.15	964.80	1136.2	1091.80
13	2163.02	980.50	1143.5	1092.60
14	2168.22	986.10	1162	1096.40
15	2171.58	1008.10	1163.4	1111.70
16	2179.96	1018.90	1208.6	1116.40
17	2184.45	1022.90	1237	1124.70
18	2185.27	1058.70	1246.6	1130.50
19	2189.58	1070.40	1271.6	1132.80
20	2192.41	1082.00	1289.6	1136.70
21	2192.44	1102.80	1301.1	1139.80
22	2193.08	1126.00	1317.1	1156.70
23	2193.98	1136.20	1339.4	1175.20
24	2196.25	1151.90	1358.8	1215.70
25	2202.48	1209.80	1374.2	1227.80
26	2266.09	1224.60	1417.8	1231.60
27	2271.23	1229.60	1448	1294.80
28	2280.63	1251.90	1512.5	1299.10
29	2281.27	1253.90	1530.2	1319.30
30	2295.39	1266.60	1533.4	1331.00
31	2297.52	1293.40	1581.2	1364.80
32	2307.87	1306.10	1590.5	1365.00
33	2321.65	1309.00	1600.8	1369.70
34	2326.52	1320.10	1601.9	1401.90
35	2327.46	1354.40	1617.6	1410.20
36	2342.17	1360.20	1672.2	1422.10
37	2346.10	1365.00	1684.6	1456.70
38	2351.24	1368.50	1714.2	1458.30
39	2359.83	1376.00	1721.9	1468.00
40	2371.86	1383.60	1803.3	1507.10
41	2372.41	1395.10	1815.4	1530.60
42	2385.22	1411.90	1830.3	1535.10
43	2400.96	1420.00	1831.1	1556.00
44	2423.60	1420.50	1891.5	1589.10
45	2457.28	1437.60	1892.8	1638.90
46	2466.21	1439.50	1907.6	1644.10
47	2466.79	1484.60	1939.4	1655.20
48	2474.85	1565.00	2061.2	1715.10
49	2500.90	1569.70	2086.8	1722.20
50	2517.08	1608.60	2096.2	1811.70
51	2524.46	1679.60	2117.3	1898.80
52	2563.92	1742.90	2297	1933.70
53	2571.41	1775.90	2410.1	2146.80

Source: (CENAOS, 2023), (DatosMundial, 2023), (INETER, 2023), (WorldClim, 2023)

The statistical analysis of correlation is conjugated from the variable Y as the dependent variable in this case the WorldClim data versus three independent variables in this case the data from the stations in Nicaragua, Costa Rica and Honduras. Itstarts from the following equation 1, see table 3.

$$Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3 \quad \text{equation 1}$$

Where:

Y = WorldClim dependent variable
b_0, b_1, b_2 = multipliers or correlation coefficient
X_1, X_2, X_3 = independent variables.

Table 3: Result of the combination of AND as Dependent Data WorldClim

Regression Statistics	
Multiple correlation coefficient	0.992616997
Determination coefficient R ^ 2	0.985288502
R ^ 2 adjusted	0.984387798
Typical error	18.51376303
Observations	53
Coefficients	
Interception	1692.141097
Variable X 1	0.070414031
Variable X 2	0.292750521
Variable X 3	0.045092026

Note: application of expression 1, the data was processed in Microsoft Excel

In case two, the hypothesis of variables dependent on the data from the Nicaragua station is proposed, and the other databases as independent data. See table 4.

Where:

Y = dependent variable Station Nicaragua
b_0, b_1, b_2 = multipliers or correlation coefficient
X_1, X_2, X_3 = independent variables.

Table 4: Result of the Combination of Y as Dependent data Station Nicaragua

Regression Statistics	
Multiplecorrelationcoefficient	0.99080164
Determinationcoefficient R ^ 2	0.9816879
R ^ 2 adjusted	0.98056675
Typical error	36.6662142
Observations	53
Coefficients	
Interception	-212.430625
Variable X 1	0.27618618
Variable X 2	0.61337983
Variable X 3	-0.08863901

Note: application of expression 1, the data was processed in Microsoft Excel

In case three, the hypothesis of dependent variables is proposed, the data from the Costa Rica station, and the other databases as independent data. See table 5.

Where:

Y = dependent variable Station Costa Rica
b_0, b_1, b_2 = multipliers or correlation coefficient
X_1, X_2, X_3 = independent variables.

Table 5: Result of the Combination of AND as Dependent Data Station Costa Rica

Regression Statistics	
Multiple correlation coefficient	0.996108937
Determination coefficient R^2	0.992233015
R^2 adjusted	0.991757485
Typical error	36.11292278
Observations	53
Coefficients	
Interception	-2136.585477
Variable X 1	0.595007754
Variable X 2	1.113867553
Variable X 3	0.279408289

Note: application of expression 1, the data was processed in Microsoft Excel

The last case proposes the hypothesis of variables dependent on the data from the Honduras station, and the other databases as independent data. See table 6.

Where:

Y = dependent variable Station Costa Rica

b_0, b_1, b_2 = multipliers or correlation coefficient

X_1, X_2, X_3 = independent variables.

Table 6: Result of the Combination of AND as Dependent Data Station Honduras

Regression Statistics	
Multiple correlation coefficient	0.980746102
Determination coefficient R^2	0.961862916
R^2 adjusted	0.959527993
Typical error	55.7493155
Observations	53
Coefficients	
Interception	-338.2848118
Variable X 1	0.408873935
Variable X 2	-0.204914086
Variable X 3	0.665875578

Note: application of expression 1, the data was processed in Microsoft Excel

Four possible combinations were produced, making Y the global data from WorldClim, the precipitation data from the Nicaragua station, the precipitation data from the Costa Rica station, and the precipitation data from the Honduras station, for each of the combinations made, an R2 correlation was obtained. fitted around 0.98, 0.98, 0.99, and 0.95 respectively, indicating a very precisely corrected measure of goodness-of-fit and that the model is collectively explained by all independent variables.

Regarding the typical error, a variation is observed for each of the combinations, which have the following magnitudes 18.51, 36.66, 36.11 and 55.74, this tells us how well the studied data fit, reaching a maximum value when deviating from the mean of the sample analyzed with respect to the mean of the total population.

Figures 2, 3, 4 and 5 can be seen to see the correlation trend.

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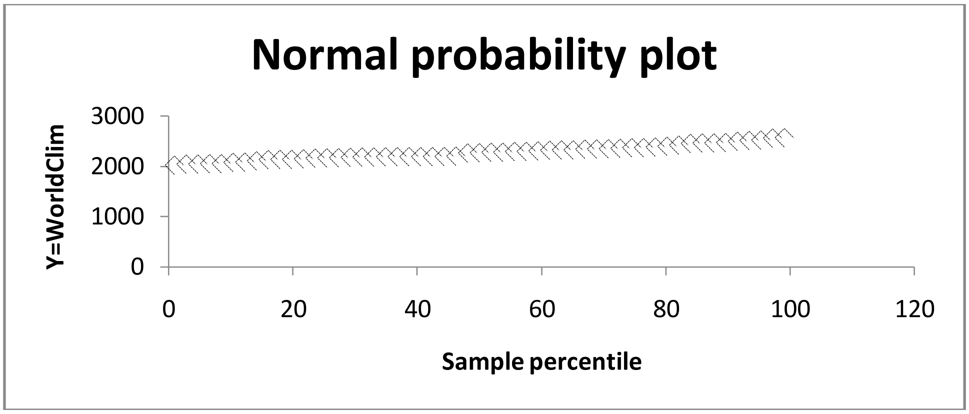
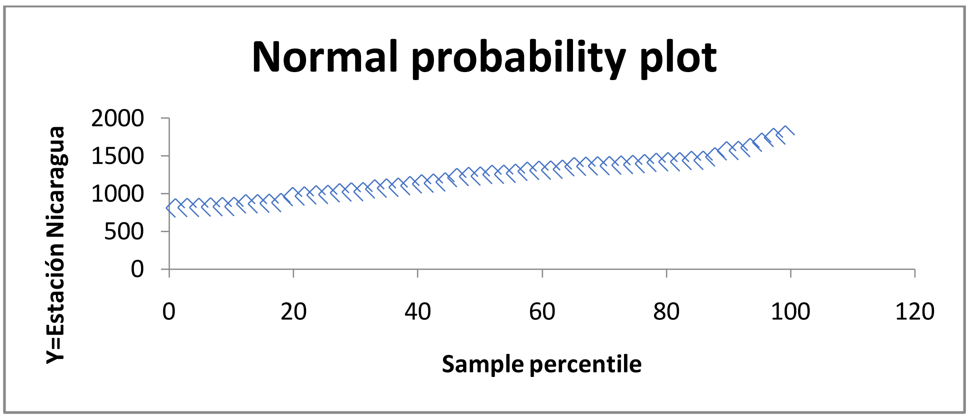


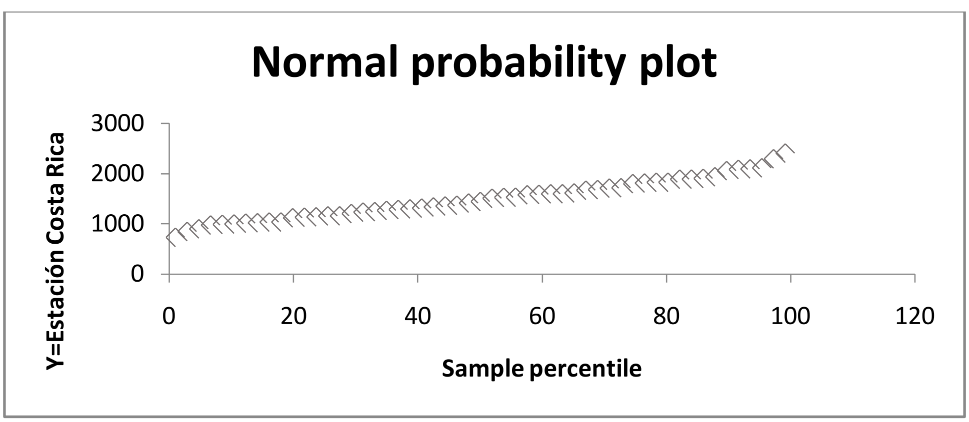
Note: Own Elaboration Obtained from the Modeling in Microsoft Excel

Figure 2: Behavior of the trend with the variable Y worldClim



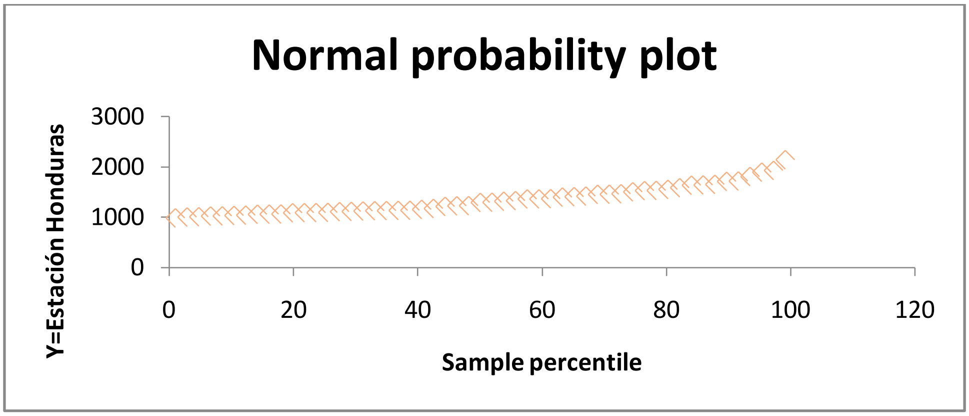
Note: Own Elaboration Obtained from the Modeling in Microsoft Excel

Figure 3: Behavior of the Trend with the Variable Y Station Nicaragua



Note: Own Elaboration Obtained from the Modeling in Microsoft Excel

Figure 4: Behavior of the Trend with the Variable Y Station Costa Rica.



Note: Own Elaboration Obtained from the Modeling in Microsoft Excel

Figure 5: Behavior of the Trend with the Variable Y Station Honduras

The normal probability graphs for each of the combinations represent the behavior trend, its trend is linear. No variable momentum is observed that makes the data unscattered and maintains a strong correlation.

VII. Conclusion

The analysis of the correlation of the historical precipitation variables of Nicaragua, Costa Rica, Honduras versus the global historical precipitation of WorldClim, produced four possible combinations using the multivariate statistical analysis technique of correlation analysis, where Y were the global data of WorldClim, the Nicaragua station data, the Costa Rica station data, and the Honduras station data, with correlation magnitudes of R2 098, 0.98, 0.99, and 0.95, respectively.

According to the results, the goodness-of-fit correlation measure indicates a lot of precision in the different combinations, and that the model is collectively explained by all the independent variables, being able to use the global historical data from WorldClim with two other random stations to to be able to carry out a punctual hydrological analysis in the absence of information.

Gratitude

First of all, to God, our father, who has given me a hand to continue on the right path and achieve my goals.

To my mother Beatriz Picado, for showing me the way to success.

To my sons DafnedItziar Tirado Flores and Víctor Manuel Tirado Flores, I will always be their guide, to my grandson Ezio, welcome.

To my wife, Lisseth Carolina Blandón Chavarría, who trusts in my successes, thank you for being by my side.

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Memberships

FELLOWS/ASSOCIATES OF SCIENCE FRONTIER RESEARCH COUNCIL

FSFRC/ASFRC MEMBERSHIPS

Introduction

FSFRC/ASFRC is the most prestigious membership of Global Journals accredited by Open Association of Research Society, U.S.A (OARS). The credentials of Fellow and Associate designations signify that the researcher has gained the knowledge of the fundamental and high-level concepts, and is a subject matter expert, proficient in an expertise course covering the professional code of conduct, and follows recognized standards of practice. The credentials are designated only to the researchers, scientists, and professionals that have been selected by a rigorous process by our Editorial Board and Management Board.

Associates of FSFRC/ASFRC are scientists and researchers from around the world are working on projects/researches that have huge potentials. Members support Global Journals' mission to advance technology for humanity and the profession.

FSFRC

FELLOW OF SCIENCE FRONTIER RESEARCH COUNCIL

FELLOW OF SCIENCE FRONTIER RESEARCH COUNCIL is the most prestigious membership of Global Journals. It is an award and membership granted to individuals that the Open Association of Research Society judges to have made a 'substantial contribution to the improvement of computer science, technology, and electronics engineering.

The primary objective is to recognize the leaders in research and scientific fields of the current era with a global perspective and to create a channel between them and other researchers for better exposure and knowledge sharing. Members are most eminent scientists, engineers, and technologists from all across the world. Fellows are elected for life through a peer review process on the basis of excellence in the respective domain. There is no limit on the number of new nominations made in any year. Each year, the Open Association of Research Society elect up to 12 new Fellow Members.

Benefit

To the institution

Get letter of appreciation

Global Journals sends a letter of appreciation of author to the Dean or CEO of the University or Company of which author is a part, signed by editor in chief or chief author.

Exclusive Network

Get access to a closed network

A FSFRC member gets access to a closed network of Tier 1 researchers and scientists with direct communication channel through our website. Fellows can reach out to other members or researchers directly. They should also be open to reaching out by other.

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Certificate

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RECOGNITION ON THE PLATFORM

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Certificate, LoR and Momento 2 discounted publishing/year **Gradation** of Research 10 research contacts/day 1 **GB** Cloud Storage **GJ** Community Access	**Certificate,** LoR and Momento **Unlimited** discounted publishing/year **Gradation** of Research **Unlimited** research contacts/day 5 **GB** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**Certificates,** LoRs and Momentos **Unlimited** free publishing/year **Gradation** of Research **Unlimited** research contacts/day **Unlimited** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**GJ** Community Access

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We accept the manuscript submissions in any standard (generic) format.

We typeset manuscripts using advanced typesetting tools like Adobe In Design, CorelDraw, TeXnicCenter, and TeXStudio. We usually recommend authors submit their research using any standard format they are comfortable with, and let Global Journals do the rest.

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2. Authors must accept the privacy policy, terms, and conditions of Global Journals.
3. Ensure corresponding author's email address and postal address are accurate and reachable.
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- Any other original work

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2. Drafting the paper and revising it critically regarding important academic content.
3. Final approval of the version of the paper to be published.

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Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

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Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

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Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

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Techniques for writing a good quality Science Frontier Research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of science frontier then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

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7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

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Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.

22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.

23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.
- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- o Single section and succinct.
- o An outline of the job done is always written in past tense.
- o Concentrate on shortening results—limit background information to a verdict or two.
- o Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

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Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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