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## A Study to Determine the Effects of Lengthy Space Exposure on Tomato Seeds and Plants

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**A STUDY TO DETERMINE THE  
EFFECTS OF LENGTHY SPACE EXPOSURE ON  
TOMATO SEEDS AND PLANTS**

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**A RESEARCH PROJECT  
PRESENTED TO THE FAULTY OF THE COLLEGE OF EDUCATION  
OLD DOMINION UNIVERSITY**

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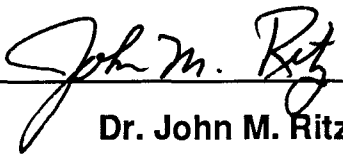
**IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR THE DEGREE  
MASTER OF SCIENCE IN EDUCATION**

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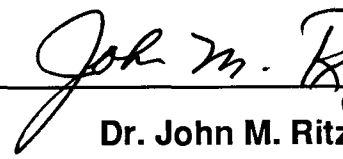
**BY  
DANIEL ROBERT SMITH  
JULY, 1990**

This project was prepared by Daniel Robert Smith under the direction of Dr. John M. Ritz in VTE 636, Methods of Research in Vocational Education. It was submitted to the Graduate Program Director as partial fulfillment of the requirements for the Master of Science in Education in Education degree.

APPROVED BY:

  
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## **ACKNOWLEDGEMENTS**

**I am grateful for the support and assistance of many people in completing this research study. I would first like to thank my research advisor, Dr. John M. Ritz, Old Dominion University, for his help, encouragement and patience throughout the project.**

**I appreciate the time and attention to detail demonstrated by two Blair Middle School Technology Student Aides, Jesse Robbins and Beth Morgan. Their efforts in data collection, plant and growth unit maintenance and promotion of the Blair Technology Program in conjunction with this project was invaluable. They both preformed admirably while serving in dual roles, assistant and student, allowing me the opportunity to not only learn but also teach.**

**Finally, my deepest gratitude goes to my wife, Fran, and my daughter, L. C. Fran was always there with an answer and L. C. with a smile.**

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## **CHAPTER I**

### **INTRODUCTION**

**President Bush envisions American outposts on the moon and Mars with a script that would have four humans arriving on the red planet in 2011 and returning for a 600-day stay in 2018. This was revealed in a NASA study delivered to the National Space Council in the Fall of 1989. The report further stated that the space station, Freedom, which is scheduled to be completed in 1999, would become "a transportation node where both lunar and Mars vehicles will be assembled, tested, launched and refurbished to fly again." (Associated Press, 1989, A60) It would appear, by the funding being recommended for the Mars and space station Freedom programs in the federal budget for fiscal year 1991, that President Bush is going to make this vision a reality.**

**Before this vision is realized, however, there are numerous elements with which to be dealt. Top priority of any manned space mission or colony is to provide a complete life support system. This system must be capable of supplying sufficient oxygen, food, and water, and removal of excess carbon dioxide, water vapor, and human body waste.**

**This paper deals with one aspect of the life support**

system, food. Specifically, how will seeds or plants be affected by extended space travel?

The seven-to thirty-day missions normally undertaken by the space shuttle is not enough time to gather data concerning the prolonged effects of space upon materials of which these proposed missions will endure. So a special twelve-sided cylinderlike free-flying structure, called the Long Duration Exposure Facility (LDEF), was built. Basically, the LDEF is a drumlike framework that can hold up to seventy-two experiments. (Coombs, 1979, p. 90)

More than five years ago, along with fifty-six other experiments, LDEF was placed into a geocentric orbit with a project named Space Exposed Experiment Developed for Students (SEEDS). See Figure 1. The project placed 12.5 million tomato seeds in orbit. (NASA, 1989, p. 3) Upon its return in January of 1990, the seeds were made available to various educational sectors. A portion of these flight seeds were planted at Blair Middle School in Norfolk, Virginia and compared to a control group of seeds planted under the same conditions in order to record some of the effects of long-duration space exposure.



Figure 1. LDEF Orbiter

## **STATEMENT OF PROBLEM**

The problem of this study was to determine the effects of lengthy space exposure on tomato seeds and plants.

## **RESEARCH HYPOTHESIS**

Through the analysis of the data collected from the identical planting techniques of the flight seeds verses the control seeds, the following hypothesis was considered:

*H1-The tomato seeds of the SEEDS program will produce genetically altered mutant plants.*

## **BACKGROUND AND SIGNIFICANCE**

The foundation for space travel was laid in 1923. In that year Professor Hermann Oberth, the "father of space travel," published his first book in Munich with the arresting title, By Rocket into Planetary Space. Professor Oberth's book not only

discussed scientifically, space travel, but also provided detailed projections on the construction and operation of a space station. The space station's primary purpose is to make more distant space travel simpler. As stated previously, any manned space travel must first deal with meeting the basic biological needs of man. On the subject of food, Professor Oberth had plenty to say. He suggested the cultivation of plants, and in particular algae. Algae, he surmised was the best selection because it multiplied at such a fast rate, supplying oxygen and food; it would eliminate the many costly transport missions to deliver such necessities. (Oberth, 1957, p. 89) Yet, as sound as Professor Oberth's proposals were, much was to evolve concerning food management.

Since the first manned space flight of the 1950's and through the 1980's, the emphasis has been on transporting food from Earth as opposed to generating food onboard a space vehicle. This occurrence has not been for the lack of trying, however. Great efforts have been expended to reconstitute food from waste products and bacteria. There has been progress, but to date these methods have proved unacceptable. Even Professor Oberth's idea of algae has been researched yielding the following results: " The culture of algae, once projected as a 'space food,'

is rejected as a major source of nutrition, because of algae's inherent low productivity and lack of attractiveness and variety." (Engineering System Design Fellows, 1977, p. 230) Thus far, food management has involved techniques for storing, heating, chilling, and serving food rather than a system of food cultivation.

The projected long distance and long-duration flights could maintain the status quo in regards to providing food to the astronauts; but for a number of reasons many space researchers feel these new programs will require a different approach. Even though the shuttle is capable of transporting food; food is heavy. A year's supply of food for four persons, carefully selected for nutrition, taste, and minimum weight, with all the moisture removed, would weight about 2,400 pounds. (Mc Donald, and Hesse, 1970, p. 170) More weight means more shuttle missions which means more fuel costs, launch costs, and man hours. One does not have to be a rocket scientist to figure that the cost of keeping a pantry on the planet Mars well stocked would soon become astronomical. Additionally, what would be the results if there was a lengthy delay in a major food shipment? Jesco von Puttkamer, Program Manager, Long-Range Studies, Office of Space, wrote in The Long-Range Future about

what many space researchers believe will be the future concerning food in space. Mr. Puttkamer believes that the technology is not presently available to sustain life on large bases situated on the moon or other celestial bodies. Closed or semiclosed environments containing agricultural systems are "essential" for these bases to exist. Unequivocally, agricultural systems will replace the present system of food storage. (Bekey, and Herman, 1985, p. 379) The proposed long-duration missions are quickly approaching; the time for further research is now!

Professor Oberth's thoughts on algae may have missed the mark but his over-all plans for vegetation on long-duration missions was, not surprisingly, right on cue. As modest as this research on tomato seeds may be, it will help further secure the predictions laid out in 1923.

### **Limitations**

This study was limited to the tomato seeds, both flight and control, provided by NASA through the SEEDS program. Both seed groups were sown in identical compact, non-electric hydroponic units experiencing the same lighting and nutritional

conditions. Another limit placed upon this study was a stringent time schedule. Reports requested by NASA concerning this study and the summer closing of the Blair Technology Laboratory necessitated a nine week growing schedule.

### **Assumptions**

**This study was based on the following assumptions:**

- 1. The seeds provided will germinate.**
- 2. The flight seeds have not been exposed to any other adverse or unusual conditions other than the flight aboard LDEF. Therefore, any difference in germination rates or seedling vigor will be due to long-duration space exposure.**

### **Procedures**

**The process of the experiment involved a sequential pattern. The steps were as follows: visual observation data,**

**plant care data and plant environment data.**

**Throughout the period following the first plant sprouting, weekly data was recorded on all visual aspects of both planting sites. Plant care was administered when needed following each weekly data collection session. Determination of plant needs was based on the control plants well being.**

### **DEFINITION OF TERMS**

**Terms used in this study were defined as follows:**

**Biogeocenoses - The relation of chemicals to plant and animal life in an area.**

**Biomass - The amount of living matter.**

**CELSS - Closed Ecological Life Support System**

**Circumferential - The external boundary or surface of a figure or object.**

**Flight seeds - Tomato seeds exposed to the long-duration space environment aboard the LDEF spacecraft.**

**Hygrometer - An instrument for measuring the humidity of the atmosphere.**

**LDEF - Long Duration Exposure Facility.**

**Mutant - A significant and basic alteration.**

**NASA - National Aeronautics and Space Administration.**

**PGU - Plant Growth Unit**

**SEEDS - Space Exposed Experiment Developed for  
Students.**

## **SUMMARY**

**In Chapter I of this study, the problem and hypothesis were identified. The problem stated was to determine the effects of lengthy space exposure on tomato seeds and plants. The background and significance of the study, as well as the limitations, assumptions, and definitions of terms used within the study were also given. In addition, a brief description of the procedures used to gather pertinent data was provided.**

**In the following chapters, a review of literature pertaining to the problem was presented, along with a detailed explanation of the methods and procedures used to collect the data the experiment yielded. The final chapters reported the findings, presented a detailed analysis of the same, and gave a summary of the research study sighting conclusions made based on the data collected.**

## **CHAPTER II**

### **REVIEW OF LITERATURE**

**Chapter II will review literature published on the topic of plant-growing in space. Included in this chapter are the following subtitles: Controlled Ecological Life Support Systems (CELSS), Higher Autotrophic Plants and Plant Growing Units (PGU) .**

**From the extensive review of literature conducted concerning plant-growing in space, the most obvious fact was the interrelationship that plant production has with all the other links that allow humans to sustain life. Notwithstanding, in order to bring focus to this review, an exerted effort is, when possible, made to separate this link from the chain.**

### **CONTROLLED ECOLOGICAL LIFE SUPPORT SYSTEMS**

**In the biosphere of the earth, by using the radiant energy of the sun, green plants form organic substances by photosynthesis. They simultaneously give off oxygen and absorb carbon dioxide. Due to this unique "factory," which converts**

radiant energy into diverse substances, humans live safely on earth. Under natural conditions, complex interactions of plants and other components of the terrestrial communities, biogeocenoses, takes place. (Nikishanova, 1977, p. 5) This complex system does not exist in a space orbiter or on the surface of a planetary body, therefore a means of supplying the human dietary needs must be created. This may be accomplished by one or a combination of three methods: the materials can be stored aboard at the time of launch for the entire mission, supplies can be brought to the crew via a transportation vehicle or they can be supplied by some means of food production. The first two methods are commonly called resupply or open systems and the last method is known as regenerative, recycle or a closed system.

It was recognized early, as manned missions became longer and crew size increased, that the weight, volume and transportation penalties of storing or routinely resupplying consumables would be cost prohibitive. (Gustan, and Vinopal, 1982, p. 31) Left with the obvious, NASA created the CELSS program. The CELSS program is a long term research and development effort that addresses the future needs of NASA for recycling and regenerating materials needed for human substance

during extended space missions. (Oleson and Olson, 1986, p. 2) A current concept and considered future direction of CELSS is the use of bioregenerative life support systems. In some ways a bioregenerative system resembles an ecological system; however, the system required for life support in a location isolated from Earth cannot rely on the same kinds of reservoirs and buffering systems. To supplement this deficiency, bioregenerative systems employ microbiological and/or physical chemical techniques. (MacElroy, and Bredt,1985, p. 1) Pertaining to plant growth for bioregenerative systems two major areas of study have been conducted. The areas of study have dealt with Higher Autotrophic Plants and Plant Growth Units.

## **HIGHER AUTOTROPHIC PLANTS**

As stated in Chapter I of this study, algae was first thought to be the panacea of space food production, but research proved this not to be the case. Investigations since the 1960's have led research in the direction of higher autotrophic plants. Botanists number about 250,000 different kinds of higher flowering plants on Earth. But only 2,558 kinds are used by

humans for food. (Dadykin, 1968, p. 39) The selection is large; however, the question of which kinds should be used to create a link of higher autotrophic organisms for a closed ecological system remains.

Two NASA workshops, one in 1979 and the other in 1980, stated that crop selection should be based on the maximum quantity of digestible biomass and the minimum quantity of non-digestible biomass. (Alford, 1982, p. 13) Certain plants have been previously identified to contain these elements and are likely destined to be space food. These plants are sweet potatoes, Chinese cabbage, radish, tampala, and duckweed. (Calvin, and Gzenko, 1975, p. 42) Before these plants, or any others, can be labeled unequivocally space food material, the manner in which they will be produced and the resulting data from such a system must be factored into the complete CELSS before any determination can be made. (Alford, 1982, p. 13)

## **PLANT GROWTH UNITS**

With the realization that for long duration space missions a method of producing food would be needed, many questions

arose. How do you raise plants in space which are used not only as sources of food, but also to regenerate water and air so that they provide an uninterrupted replenishment of oxygen and removal of carbon dioxide in the atmosphere of the spacecraft? How do you protect the space garden from radiation? How much light should plants have, and with what periodicity? These, and a list of no less serious questions, have and will continue to prompt researchers to seek answers.

Initial efforts toward development of food production systems for manned spacecraft were initiated by both the United States and the Soviet Union during the late 1950's and early 1960's. (Alford, 1982, p. 1) One of the first areas of investigation concerned hydroponics. Hydroponics is the science and practice of growing plants using a solution of water and nutrients and any one of a number of other nonsoil mediums including gravel, sand and vermiculite. The term is a combination of two Greek words roughly meaning "water working." It was coined by Dr. W. F. Gericke of the University of California in 1936. In that year, Dr. Gericke succeeded in growing twenty-five-foot tomato vines in a solution of water and mineral salts. (Nicholls, 1977, p. 11)

The advantages of hydroponics include large productivity

(20 times more than the same sized square of ordinary agriculture), low water expenditure, as the water in hydroponics does not escape from the root zone and soak into the soil. Crop quality, as a rule, is higher in hydroponics than in soil culture; the crops are cleaner. Hydroponics does not need crop rotation. Providing the plants with nutrient materials is easy to control by automation and standardization.

There is, however, a serious obstacle to the use of hydroponics in space, the absence of gravity. Hydroponics, which is simple on Earth, is greatly complicated under weightless conditions. On Earth it is simple to flood the growing medium or substrate with the nutrient solution. Under weightless conditions, liquid cannot be poured out of a container; it must be fed to the substrate under some pressure. Bearing this obstacle in mind, research has been directed toward a presently preferred method called aeroponics.

Aeroponics, like hydroponics, is a soilless gardening method where plants are fed by means of a water and nutrient mix. Yet, there are two major differences that make aeroponics better suited for use in space. The first difference is that plants are sprayed with the nutrient solution periodically as opposed to sitting in a tank of solution. This elevates the

gravity problem associated with hydroponics. Secondly, aeroponics uses no substrate, but instead has the base of the plant secured, leaving the roots untethered. This has the tremendous advantage of allowing for plant movement which can be used to economize much needed room aboard a spacecraft or living module. (Dadykin, 1968, p. 45-50)

Although considerable research had been conducted in the area of food production in space, the NASA CELSS program concluded by the early 1980's that data base gaps existed to the point that specific inventions could not be built and tested for long duration space missions. Therefore, a study was conducted by Boeing Aerospace Company titled the "Regenerative Life Support/Controlled Ecological Life Support Mission Model Study." The study, released in 1986, addressed these data base gaps by developing and analyzing a series of conceptual designs. As crew time is a critical resource, all of the Plant Growth Units (PGU) produced by the study were highly automated so as to only require human attention in the event of equipment failure or severe plant damage.

The study yielded ten different PGUs. A brief description of these units follow:

1. Conveyor-belt PGU uses two conveyors facing a

common light source. Plants grow as the conveyor belt slowly moves.

2. Honeycomb tray PGU has six-sided trays facing toward six-sided light sources. Plants grow on two or three sides depending on tray location in pattern. Trays plug in longitudinally to growth unit.

3. Parallel-to-hull PGU grows plants in a false wall between module interior and hull. A robot travels against the hull, is short and long, and carries the harvester with it.

4. Accordion tray PGU has trays on vertical racks accessible from an aisle. The racks extend from aisle to module inner hull surface. This creates progressively deeper slots with deepest slot at the module center line. Trays are built with accordion folds so they may be collapsed to fit the shallow top slot. The trays are moved to deeper slots as plants mature. This allows the tray to be expanded, thereby providing more plant growth area per tray. Trays are moved from slot to slot and finally to the harvester by robot. See Figure 2.

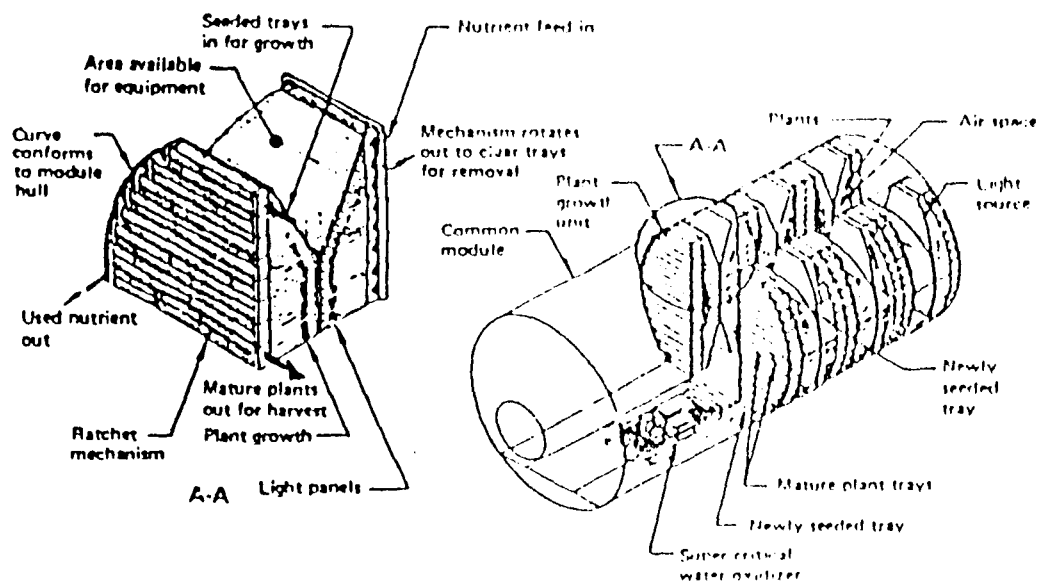


Figure 2. Accordion Tray Concept

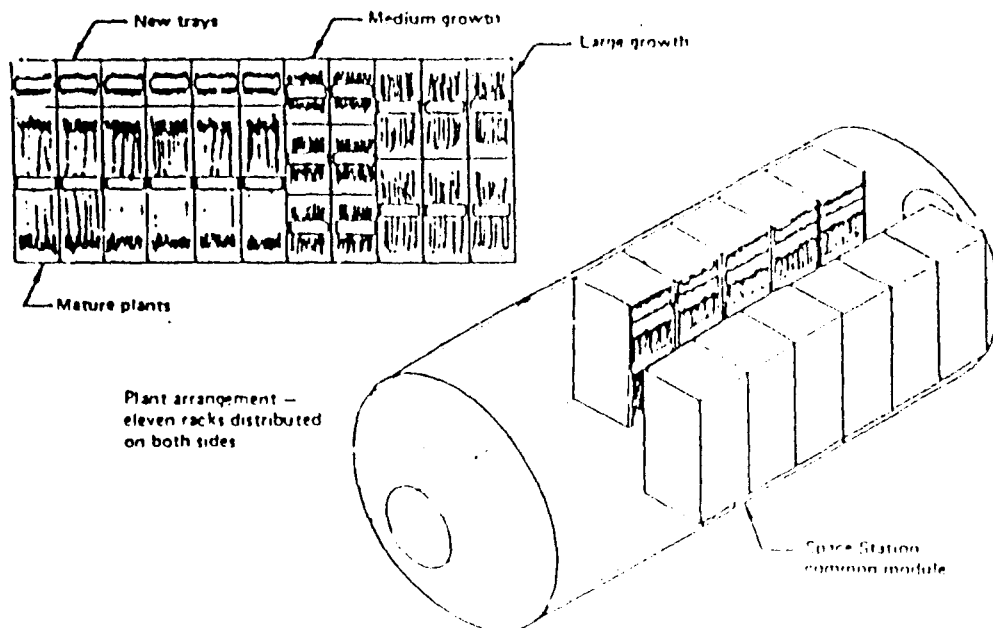


Figure 3. Automated Warehouse Concept

5. Cone-shaped PGU has a continuous tray moving through a cone with the light source facing inward from the cone surface. Growth surface is a collapsible continuous tube.
6. Radial tray PGU places trays facing outward from the module center with the robot at the center. Circumferential arrangement of trays uses the large available surface area for plant growth.
7. Baloney slice PGU has vertical panels that grow plants on their sides. As plants grow, panels move laterally to allow growth and adjust lighting distance from plant.
8. Clamshell PGU grows plants on a core facing toward the inside of a sphere that has a light source. Plants grow on most of the core excluding only the tube that supports the core and provides nutrient plumbing.
9. Rotating drum PGU has a slowly rotating drum. Seeding and harvesting are performed continuously as the drum rotates.
10. Warehouse tray PGU has trays on vertical racks serviced by a robot that moves along the center aisle. Trays fit into different slots, which places lights as close to plant while allowing for growth. As plants grow, the robot moves the trays into

progressively larger slots that accommodate growth. See Figure 3.

After a review of the data compiled concerning each unit NASA selected the Accordion tray as the best CELSS PGU concept. This selection was made by focusing on the PGU system that would provide the best volume and power utilization while keeping costs and manpower requirements to a minimum. This concept will be the basis for future preliminary designs. (Oleson, and Olson, 1986, p. 23-31)

### Summary

Chapter II presented research material that existed concerning plant-growing in space. The reasons for, and the parameters of, a Closed Ecological Life Support System were detailed. Also, information describing the criteria for Higher Autotrophic Plants, including some candidate crop selections was provided. Lastly, details covering the technology by which plants will be tested and ultimately produced, the Plant Growth Units, was presented.

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## **CHAPTER III**

### **Methods and Procedures**

The problem of this study was to determine the effects of lengthy space exposure on tomato seeds and plants. This chapter explains in detail the methods and procedures used to collect this information. Following are sections on the experiment groups, experiment procedures, methods of data collection, and summary.

#### **EXPERIMENT GROUPS**

Two groups of tomato seeds were used in this experiment, flight seeds and control seeds. As stated in Chapter II of this study, tomato plants are not presently prospective candidates for cultivation in space. However, for several reasons tomato seeds were selected for LDEF. Their small size permitted a large number to be flown, they are from a familiar plant and tomato plants are relatively hardy and can be grown throughout the United States.

The particular tomato seed selected was Rutgers California Supreme (*Lycopersicon lycopersicum*). Rutgers

tomatoes were developed in 1935 at Cook College of Rutgers University by Professor Lyman G. Schermerhorn. Rutgers tomatoes are a nonhybrid variety that will produce plants with relatively little variation in successive generations. Consequently, changes in plant expression possibly resulting from space exposure will be more easily detected.

Both the flight and control seeds were mechanically defuzzed by tumbling the seeds in a spinning drum. This process reduced the volume and weight per seed thus allowing additional seeds to be flown. Defuzzing does not affect the germination rate of tomato seeds.

Twelve and one-half million tomato seeds provided by the Park Seed company were sealed in five aluminum canisters approximately 1 cubic decimeter (1 cubic foot) in volume. The seeds were packed in Dacron bags forming four layers per container. The containers were sealed at 1013.25 millirads (14.7 psi) atmospheric pressure and 15% humidity. The container domes were approximately .127 centimeters (.050 in) in thickness.

Passive detectors were placed in each canister to record the highest interior temperature and accumulated radiation. For thermal control, each canister was painted white on the top and sides and black on the bottom. Additionally, the tray was closed

with a thermal cover. The temperature range inside each canister was -23 degrees C to 35 degrees C (-10 degrees F to 95 degrees F). The radiation detectors were placed above and below each layer of seeds. Radiation levels at the orbital altitude of the LDEF is approximately 100 millirads. This is the equivalent to several x-rays. The canisters were secured in a tray mounted adjacent to the space-facing end of LDEF.

An equal number of tomato seeds from the same seed lot was placed in storage at the Park Seed Company facilities located in Greenwood, South Carolina. The seeds were stored at 21 degrees C (70 degrees F) at 20% relative humidity.

The flight and control seeds were produced by plants subjected only to the natural radiation of their environment. All seeds were produced during the same growing season and were chosen from a seed lot with a high-germination rate. The seeds received no chemical treatment. (NASA, 1990, p. 4-8)

## **EXPERIMENT PROCEDURES**

The experiment was conducted in the Technology Education Laboratory, Room 104, at Blair Middle School in Norfolk, Virginia. The SEEDS kit, Identification Number 10610,

containing 48 flight seeds and 57 control seeds arrived at Blair March 26, 1990. Both the flight seeds, from canister 7, layers A, B, C and D mixed and the control seeds were planted on March 28, 1990, in identical hydroponic greenhouse units. Prior to planting the seeds, the hydroponic units, which measure 14 in. x 9 in. x 3 in., were prepared using a substrate of vermiculite and nutrient solution. The nutrient solution consisted of 1/2 a teaspoon of nutrient mix per gallon of water for each unit. The units reservoirs hold one gallon of nutrient solution. Each unit was filled to capacity. Subsequent nutrient solution refills employed a mixture of one teaspoon per gallon. The nutrient mix bears the brand name of Hydroponic Plant Food and it is manufactured by U. M. I., Inc. of Culver City, California. Listed below are the properties contained in the nutrient mix. This listing is a duplication of the product contents label.

**Nutrient Mix-Guaranteed Analysis of 10-8-22**

<b>Total Nitrogen(N)</b>	<b>10.0%</b>
<b>Nitrate Nitrogen(Min)</b>	<b>8.0%</b>
<b>Ammonical Nitrogen(Max)</b>	<b>2.0%</b>
<b>Available Phosphoric Acid(P<sub>2</sub>O<sub>5</sub>)</b>	<b>8.0%</b>
<b>Soluble Potash(K<sub>2</sub>O)</b>	<b>22.0%</b>
<b>Calcium</b>	<b>5.0%</b>

**Magnesium .....1.0%**  
**Sulfur ..... 3.0%**

The units were placed on a four foot elevated stand in front of a window measuring 9 ft. x 6 ft. having a western exposure. Supplemental lighting for each unit was provided by gro-lites (fluorescent tubes that project a color spectrum range equivalent to that found in a ray of sunlight) with 125-watt bulbs.

### **METHODS OF DATA COLLECTION**

Comparative data was collected and recorded for the following growth responses: germination rates and growth measurements. Additional data was collected and recorded reporting the average weekly temperature and relative humidity. Further, plant and growth unit maintenance and care information was recorded.

The germination rate data was collected by visual observation. This data included the percentage of seeds that germinated 14 days after planting and the average number of

days required for those seeds to germinate.

After the germination rate data was collected, all but six seedlings were displanted. This was done to allow for adequate growing space. Seedlings left standing were selected on the basis of their proximity to six plant supports that were attached prior to planting.

Average growth measurements for the height and width of plants in centimeters was collected. The first measurements were made 14 days following sowing. The final seven measurements were taken at one-week intervals beginning on the 21st day.

## **SUMMARY**

In summary, this chapter described the methods and procedures used for collecting the research data necessary for the stated problem. Chapter IV details the findings from the experiment that was undertaken at Blair Middle School.

## **CHAPTER IV**

### **FINDINGS**

The problem of this study was to determine the effects of lengthy space exposure on tomato seeds and plants. Chapter IV reveals the results of the data collected from the experiment undertaken. Included in this chapter are the following subtitles: Germination Rates, Growth Measurements, Temperature and Relative Humidity Readings and Plant and Growth Unit Maintenance. Also included are tables displaying data concerning the growth measurements and the temperature and relative humidity readings.

#### **GERMINATION RATES**

Visual observation was employed to determine the germination rates for both groups of seeds. On the sixth day after planting, the first shoots appeared in both growing units. At the end of 14 days 42 of the 48 flight seeds (88%) and 49 of the 57 control seeds (86%) had germinated. The average number of days for those seeds to germinate was 9 days for the flight seeds and 10 days for the control seeds.

## **MEAN WEEKLY GROWTH MEASUREMENTS**

On the fourteenth day after planting, the seedlings were thinned to six per growth unit and the first weekly growth measurements was noted. Growth measurements included both height and width. Each plant was measured and the mean in each category was determined for both groups of plants. All measurements were taken using the same metal metric rule and recorded in centimeters.

Table I shows the results of the eight weekly mean height measurements. The height was measured using the substrate as the baseline and the uppermost part of the stalk as the top. The total mean height for the flight plants was 11.36 cm. The total mean height for the control plants was 8.73 cm. To determine if the difference between the two means is significant a t-test was administered. The t-test score was  $t = 1.02$  at .10%.

Table II shows the results of the eight weekly mean width measurements. The width was measured diagonally from tip to tip of the two broadest leaves. The total mean width for the flight plants was 8.35 cm. The total mean width for the control plants was 7.17 cm. Again, to determine if the difference between the two means was significant, a t-test was administered. The t-test score was .67 at .10%.

TABLE I

GROWTH MEASUREMENTS

WEEKLY MEAN HEIGHT

Week/Date	Flight Seeds	Control Seeds
2 4-08-90	3.36	3.02
3 4-15-90	5.84	4.46
4 4-22-90	6.29	5.04
5 4-29-90	10.03	8.26
6 5-06-90	14.00	10.30
7 5-13-90	14.33	10.57
8 5-20-90	18.20	13.32
9 5-27-90	18.83	14.90

Note: Measurements in cm (centimeters).

TABLE II

GROWTH MEASUREMENTS

WEEKLY MEAN WIDTH

Week/Date	Flight Seeds	Control Seeds
2 4-08-90	3.70	3.50
3 4-15-90	4.11	3.70
4 4-22-90	4.98	3.70
5 4-29-90	7.22	5.43
6 5-06-90	9.85	7.13
7 5-13-90	12.01	8.58
8 5-20-90	12.20	10.48
9 5-27-90	12.75	11.12

Note: Measurements in cm (centimeters).

At no time during the weekly measurement sessions was there any noticeable visual difference in general plant appearance between the two groups of plants. The stalk formations, leaves and coloring for both groups were alike in all respects.

### TEMPERATURE AND RELATIVE HUMIDITY

Throughout the time period that the weekly growth measurement data was collected, daily temperature and relative humidity readings were recorded. Readings were taken each weekday at 9:00 AM and again at 1:00 PM. A mercury thermometer and a hygrometer were positioned between the two growth units.

Table III shows the weekly mean morning and afternoon temperature and relative humidity readings. In Fahrenheit, the total mean morning temperature during the experiment was 73.5 degrees and the total mean afternoon temperature was 75 degrees. The total mean morning relative humidity reading was 51 and the total mean afternoon reading was 48.

TABLE III

TEMPERATURE AND RELATIVE HUMIDITY  
WEEKLY MEAN READINGS

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Week/Date	AM Temp/Hum	PM Temp/Hum
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2 4-08-90	75/50	75/44
3 4-15-90	75/36	76/33
4 4-22-90	79/50	74/52
5 4-29-90	73/51	74/49
6 5-06-90	73/50	73/51
7 5-13-90	73/51	78/50
8 5-20-90	72/54	74/52
9 5-27-90	68/69	72/54

Note: Temperature in F units (Fahrenheit).

## **PLANT AND GROWTH UNIT MAINTENANCE**

**In accordance with the growth unit manufacturers recommendation, twice the reservoirs were emptied and the growth units flushed. This maintenance was advised to remove any salt or chemical build-up. The reservoirs were then filled to capacity with a nutrient solution consisting of one teaspoon of nutrient mix per gallon of water. These maintenance operations occurred on 4-26-90 and 5-15-90.**

## **SUMMARY**

**This chapter reported the data collected during the nine week experiment. Information concerning the germination rates and the plant and growth unit maintenance was provided. Statistical data dealing with growth rates, temperature and relative humidity was noted both in text and in tables. Chapter V provides a summary of this study along with conclusions and recommendations that resulted from the interpretation of the collected data.**

## **CHAPTER V**

### **SUMMARY, CONCLUSIONS AND RECOMMENDATIONS**

**In this, the final chapter of this study, an overview of the preceding four chapters is provided. Also, based on the findings of the experiment conducted, the testing of the research hypothesis is presented. Lastly, practical suggestions for the implementation of this study's findings and suggestions concerning areas of additional research are included.**

#### **SUMMARY**

**In Chapter I, Introduction, the prospect of extended space exploration and settlement is presented. Having established the likelihood of such future events, the need to ensure sufficient life support systems is reviewed. With this platform presented, the chapter turns to the focus of this study, specifically, how will seeds or plants be affected by extended space travel. Finally, information leading up to and the experiment (the germination and comparison of tomato seeds and plants that spent almost six years in space aboard the LDEF Orbiter verses Earth bound seeds) are outlined.**

**An extensive review of literature published on the topic of plant-growing in space is the theme of Chapter II. Included in this chapter are the following subtitles: Controlled Ecological Life Support Systems (CELSS), Higher Autotrophic Plants and Plant Growing Units (PGU) .**

**The title of Chapter III is Methods and Procedures. This chapter explains in detail the methods and procedures used to determine the effects of lengthy space exposure on tomato seeds and plants. There are three primary sections contained within this chapter: Experiment Groups, Experiment Procedures and Methods of Data Collection.**

**Chapter IV, Findings, revealed the results of the data collected from the experiment undertaken. Included in this chapter were the following subtitles: Germination Rates, Growth Measurements, Temperature and Relative Humidity Readings and Plant and Growth Unit Maintenance. Also included were tables displaying data concerning the growth measurements and the temperature and relative humidity readings.**

## **CONCLUSIONS**

**Through the analysis of the data collected from the**

identical planting techniques of the flight seeds verses the control seeds, the following hypothesis was considered:

*H1-The tomato seeds of the SEEDS program will produce genetically altered mutant plants.*

While the general appearance of the plants did not differ and the germination rates and number of days to germinate for the flight seeds were only slightly accelerated compared to the control seeds, there was a significant difference in growth rates. This difference in growth rates strongly supports this hypothesis.

The t test pertaining to the mean height of both groups yielded  $t = 1.02$ , this comparison demonstrates a very significant difference at .10%. With the t-ratio calculated for the mean width of both groups as  $t = .67$ , the significance at .10% is moderate.

The seeds were identical, the growth environments and care provided was in every detail alike for both groups of seeds and plants. The only conclusion to be drawn from the difference in the behavior of the two groups is that the extended space exposure endured by the flight seeds caused them to become genetically altered mutant plants. This mutation

taking the form of an excited growth rate.

## RECOMMENDATIONS

Based on the conclusion that extended space exposure does cause plant mutation, there can only be one reasonable recommendation. That recommendation is that extended and more detailed studies must be conducted in this area.

As stated in the limitations section of Chapter I, restrictions placed on this study did not allow sufficient time to permit the plants to bear fruit. The seeds from the LDEF Orbiter produced mutant plants. One of many questions left unanswered by this study is will the fruit of these mutant plants be muted as well. If the fruit is muted, what form will this mutation take? The ramifications are grave. If the fruit proves to be edible, and only grows at a faster pace as the plants did, then seeds exposed to an extended space environment could be a boon to both space and Earth agriculture. On the other hand, if the fruit is not edible, this could be a serious setback to planned lengthy space travel.

This study has answered a vital question pertaining to one of the essential elements of the human life cycle during

extended space ventures. However, as often is the case, the answering of one question poses countless more. These questions must be answered with further studies.

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