# *LTA 5*

*NASA - AMATYC - NSF*
*Project Coalition*

*Kennedy Space Center*

**Toxic Waste Remediation**
**at the Kennedy Space Center!**

*Mathematics for Engineering Technology*

**Industrial and Management**
**Environmental Geology**
**Materials**

*Capital Community-Technical College*

Aerial view of Swartz Road old and new landfill.

# LTA 5

## Toxic Waste Remediation at the Kennedy Space Center!

### The Situation

You have (finally) graduated from college! Now it is time to put what you have learned to good use and find a productive job. Since you were such an excellent student, many companies are actively seeking your services! You have always been interested in space exploration so you are delighted to receive an attractive offer from NASA! Firing Shuttles into outer space is pretty exciting stuff, and so you accept NASA's offer and are anxious to get to work. When you report to work, you are assigned to the office of Environmental Quality Control and are given the job of **Risk Assessor**. You are somewhat surprised to learn that NASA has an Office of Environmental Quality Control! Why would an agency whose whole purpose is exploration of space be interested in the earth's environment? You quickly learn, however, that in the process of firing rockets into outer space, many potentially toxic chemicals can be used. So your job is to help insure that the environment around Kennedy Space Center (KSC) continues to be safe for the humans, plants and animals that live there. You are also surprised that you are assigned the job of a risk assessor. You were not trained to be a risk assessor - in fact, you don't even know what a risk assessor does! You do remember that one of your college instructors coached you on the importance of being flexible, because on the job you might often be called upon to do things you were not directly trained to do while in school. So, privately, you take a deep breath, tell yourself you can do it, and enthusiastically ask your supervisor how to get started. Your supervisor recommends joining an existing group of risk assessors-in-training and gives you the article entitled **Risk Assessment 101.** So, here is what you decide to do:

1) Read the article (attached as Part 1) and answer the discussion questions, preferably with the other risk assessors-in-training in your group.
2) Do some actual risk assessment (attached as Part 2).

Remember that this is your first real job assignment so you want to do a good job and impress your supervisors.

**GOOD LUCK and HAVE FUN!!**

## Part 1
## Risk Assessment 101

Like many high technology applications, NASA's Shuttle operations can emit toxic materials into the environment. Because of this, the need to clean up these materials is a big concern to NASA. The risk assessor's job is to analyze, both scientifically and mathematically, a potentially polluted area to determine if the site should be cleaned up. The risk assessor also works with other scientists to help determine how the site should be cleaned up. In order to complete the analysis, the risk assessor needs to consider many factors. He/she needs to determine:

a) the hazardous materials which exist at the site,
b) whether or not the presence of these materials presents a potential risk to human health, and
c) whether or not the contamination at the site is so bad that it needs to be cleaned up and, if so, then how "clean" does the site need to be?

To determine what hazardous materials exist in an area, soil and water samples are taken from the site. A lab then analyzes these samples to determine if any hazardous materials are present. ***Hazardous materials*** fall into two general classes:

- **Carcinogenic materials**: These materials present a risk to human health because they have the potential to cause cancer.
- **Non-carcinogenic contaminants**: These materials do not necessarily have the potential to cause cancer, but they can cause illness or death in humans when present in concentrations above a pre-determined level.

***Hazardous materials*** can be present in:

- Soil
  When people are using the site, they can come into contact with contaminants from the soil in two ways. One way is to ingest some of the soil. (For example, you drop your grapes and eat them before all the dirt has been removed, or unseen dirt blows onto your sandwich before you eat it.) A second way is to inhale airborne particles of soil. (For example, if you disturb the ground, particles of soil become suspended in the air.)

- Surface water (ponds, lakes, rivers, etc.)
  People can be affected by contaminants in surface water through skin contact or through drinking. They can also be affected when they eat fish that come from contaminated surface water.

- Groundwater (water found underground in springs or streams between rocks)
  People can be affected by contaminants in groundwater through skin contact or through drinking. Groundwater can also seep into the surrounding soil and flow into surface water sources. If the groundwater is contaminated, this may put surrounding communities at risk.

To determine whether the presence of hazardous materials might become a risk to human health, the risk assessor needs to determine the ways in which a polluted site will be used. Will the polluted site be used for industrial, residential or recreational purposes? The risk assessor classifies the type of human activity that is occurring or may occur after NASA has left the site. Here is a list of typical classifications from which the risk assessor can choose:

i) Industrial Worker
ii) Adolescent Trespasser
iii) Adult Recreator
iv) Child Recreator
v) Adult Resident
vi) Child Resident

For each kind of human activity at the site, the risk assessor needs to determine whether the carcinogenic materials at the site pose a cancer risk to humans. For each carcinogenic material present at the site, the risk assessor calculates a value called the **Cancer Risk** due to this material. He/she then adds up the Cancer Risks for all carcinogenic materials found at a site, and this becomes the total Cancer Risk for the identified type of human activity at the site. If this number is larger than $10^{-6}$, the risk of cancer from these materials is considered unacceptable.

The risk assessor will also calculate the risk to human health due to each non-carcinogenic material at the site. He/she does this by calculating the **Hazard Quotient** for the hazardous material at the site. He/she then adds up Hazard Quotients for all non-carcinogenic materials found at a site, and this becomes the total Hazard Quotient for the identified type of human activity at the site. If this number is larger than 1, the risk from these materials is considered unacceptable.

After determining the total Cancer Risk and the total Hazard Quotient, the risk assessor will work with other scientists and managers to determine what type of clean up plan (called the Remediation Plan) should be developed. There are many options for remediation at a site. These options include:

a) **Do Nothing**: In this case you would leave the site alone, and the hazardous materials will be left to decompose. Of course this is the cheapest method of clean up, but it does not do anything to change the risk of human contact with hazardous materials.
b) **Prevent Human Contact**: You could put up a fence around the site and have it guarded. Like the first option, this does not clean up the site, but it also does not cost very much.
c) **Low Cost Remediation**: In this option you would bring the site up to standards that are minimally acceptable for human health. This is more expensive than the previous options.
d) **High Cost Remediation**: In this option you would bring the site up to standards that exceed the minimally accepted standards. This type of remediation is the most expensive.

The decision about remediation is dependent upon many factors: location of the site, cost, whether endangered species are present in the area, what type of human activity is anticipated in the future, and other political considerations.

**Discussion Questions For Your Group of Risk Assessors:**

1) In your own words summarize the process a risk assessor will undertake to determine if a site needs to be cleaned up.

2) Descriptions of polluted sites at Kennedy Space Center are given below. Discuss the type of human activity that might occur at the site and justify your answer. Keep in mind that the KSC is a government site and most areas are closed to the public.

    a) An air base near the edge of KSC grounds is discovered to be polluted. A river and a residential development each bound an edge.
    b) A landfill in the center of the KSC complex has not been used for 10 years. KSC officials are considering using the space for a future office building.
    c) An old launch pad is being redesigned to be a new museum open to the public. The beach is 500 yards from the pad.

3) As a research project, investigate one of the following hazardous materials. Write a one page article that discusses whether your material is a chemical or a metal, carcinogenic or non-carcinogenic, and how the material can be transferred to humans.
    Beryllium
    2-Hexanone
    Thallium
    Benzo(a)pyrene
    Phenanthrene
    Arsenic
    Anthracene

4) Using the World Wide Web, locate the EPA's glossary of terms at:

    www.epa.gov/ngispgm3/iris/glossary.htm

    Use the glossary to define the terms Slope Factor and Reference Dose in your own words.

## Part 2
## Doing a Risk Assessment

Now that you have completed **Risk Assessment 101**, your next step is to undertake a risk assessment of a particular site. This site is a landfill at the Kennedy Space Center (KSC) located in an area which is closed to the public.

### Hansom Landfill

This site is approximately one mile east of the Visitors Information Center. The landfill began operation in 1964 during the initial construction of KSC by NASA. During its period of operation, the landfill received unspecified waste which was placed in unlined trenches that were 600 ft x 30 ft x 10 ft. While no records of the type or quantity of materials at the landfill were maintained, it is likely that the site received a variety of hazardous waste materials. This land was also used to stockpile scrap metal and other materials on a temporary basis.

With this particular site under consideration, we first address the question of who will use the site. Since the site is an interior location at KSC in an area which is closed, we may eliminate usage by recreators or residents. Therefore, we will consider the scenario of an industrial worker at the site.

Recall from the previous section that the Cancer Risk and the Hazard Quotient are numbers that the risk assessor uses to determine a course of action. These numbers need to reflect all the factors which have an effect on the amount of risk present. Therefore, the calculations of Cancer Risk and Hazard Quotient are, by their very nature, quite involved. They will require formulas, variables, calculations, and units. We will go through the calculations one step at a time, and stop along the way to organize the information in table format. This process is presented in the following steps:

<u>Intake Rates and Exposure Assumptions</u>

<u>Calculating Intake Factors (eating, drinking and breathing)</u>

<u>Risk Calculations</u>

A. Ingestion of Soil
B. Inhalation of Airborne Soil
C. Ingesting Water

<u>Writing a Report</u>

## Intake Rates and Exposure Assumptions

Recall from the previous section that hazardous materials can be present in the soil and water at a site. These hazardous materials can threaten people who may eat or breathe in contaminated soil or drink contaminated water. Table 1 lists amounts that are considered reasonable maximum **Intake Rates (IR)** for an industrial worker at the site. It is important to note that these Intake Rates refer to the **contaminated substance** (soil, air, or water) and not to the hazardous material itself.

**Table 1 - Intake Rates**

| | |
|---|---|
| Intake Rate of ingesting (taken in orally) contaminated soil (IR) | 100 mg/day |
| Intake Rate of breathing air containing contaminated soil particles (IR) | 1.9 $m^3$/hour |
| Intake Rate of drinking contaminated groundwater (IR) | 1 *l*/day |

**ACTIVITY 1:** Translate the units for each Intake Rate into a verbal phrase. For example, mg/day would be milligrams per day. Discuss the amounts given and why these are reasonable maximum rates.

To determine the amount of contaminated substance ingested by an individual, we need to take into consideration not only the Intake Rate but also how often the individual was at the site and over what period of time. This leads to two more quantities referred to as Exposure Frequency and Exposure Duration.

- **Exposure Frequency (EF)** refers to how many days per year the person will be at the site. Exposure Frequency for an individual will vary depending on whether the site is being analyzed for use by industrial workers, residents, or recreators.
- **Exposure Duration (ED)** refers to how many years the individual will be using the site.

Now we are ready to use a formula to calculate the amount of contaminated substance ingested over a certain amount of time:

$$\text{Amount Ingested} = (\text{Intake Rate}) \times (\text{Exposure Frequency}) \times (\text{Exposure Duration})$$

Using variables, the formula is:

$$AI = IR \times EF \times ED$$

To determine this calculation for our industrial worker, let's say he/she will be working at the site for 25 years. The Exposure Duration would then be 25 years, but what about the Exposure Frequency? Risk assessors typically use the worst case scenario. If the worker only gets weekends and a few holidays a year off from work, then $250 \frac{\text{days}}{\text{year}}$ can be used for Exposure Frequency.

Using the Intake Rate from Table 1, the calculation for the maximum amount of soil ingested would then be:

$$\text{AI} = 100\frac{\text{mg}}{\text{day}} \times 250\frac{\text{days}}{\text{year}} \times 25 \text{ years} = 625{,}000 \text{ mg} = 6.25\text{E} + 05 \text{ mg}$$

There are two things to notice about this calculation:

- The cancellation of units during multiplication results in an answer that has units which are appropriate for the quantity being measured. This is called dimensional analysis.
- The final result is written in *scientific notation*.

> **ACTIVITY 2:** Referencing Table 1, perform a similar calculation to determine the maximum amount of contaminated water that an industrial worker will ingest at the site during a 25 years period. Don't forget to label your answer with the appropriate units.

AI =

Before we calculate the amount of contaminated air inhaled at the site, notice that in Table 1 the Intake Rates for breathing air are given in cubic meters per hour. Therefore, we need to include in the AI calculation another factor which reflects how many hours per day the individual will be breathing the potentially contaminated air at the site. This factor is called **Exposure Time (ET)**. The augmented formula is:

Amount Ingested = (Intake Rate) × (Exposure Time) × (Exposure Frequency) × (Exposure Duration)

> **ACTIVITY 3:** Assuming the worker puts in an 8-hour day, refer to Table 1 - Intake Rates, and calculate the maximum amount of contaminated air that an industrial worker will breathe in at the site during a 25 year period. Again, don't forget to label your answer with the appropriate units.

AI =

**ACTIVITY 4:** In order to organize the data we have accumulated so far, complete the following table by filling in the empty cells. Notice in Table 2 that the value and units for Amount Ingested by eating have been converted from mg to kg. You should verify the conversion.

**Table 2**

| **Exposure Assumption** | **Reference Variable** | **Units** | **Reasonable Maximum Exposure Value** |
|---|---|---|---|
| Intake Rate | IR | | |
| • eating | | mg/day | 100 |
| • breathing | | $m^3$/hr | |
| • drinking | | $l$/day | |
| Exposure Time | ET | | 8 |
| Exposure Frequency | | | |
| Exposure Duration | | years | |
| Amount Ingested | AI | | |
| • eating | | kg | 6.250E-01 |
| • breathing | | $m^3$ | 9.500E+04 |
| • drinking | | $l$ | 6.250E+03 |

**Calculating Intake Factors (eating, drinking, and breathing)**

Since the numbers we have calculated for Amount Ingested are based on a 25 year time frame, the risk assessor includes an averaging time to calculate the **Intake Factor**. The Intake Factor is a value that indicates the present level of danger to an individual. The impact of the Amount Ingested by an individual is influenced by the size of that the individual. In other words, a child's system would be impacted more severely than an adult's because the larger body mass of the adult allows a higher tolerance to the same level of exposure. The Intake Factor is calculated using the following formula.

$$\text{Intake Factor} = \frac{\text{Amount Ingested}}{(\text{Body Weight}) \times (\text{Averaging Time})} = \frac{\text{AI}}{\text{BW} \times \text{AT}}$$

Recall that the type of individual we are considering is an industrial worker. We will consider that the individual weighs 70 kg. (Just for fun, what is the person's weight in pounds?)

Since carcinogens may remain in the body for many, many years before they might cause cancer, the averaging time for carcinogens is taken to reflect an entire average lifetime of 70 years times 365 days per year. Thus, the Carcinogenic Intake Factor for eating would be:

$$\text{Carcinogenic Intake Factor (CIF)} = \frac{6.25\text{E} - 01\text{kg}}{70\text{kg} \times 25{,}550\text{days}} = 3.495\text{E} - 07 \frac{\text{kg}}{\text{kg - day}}$$

For non-carcinogens, the averaging time is the Exposure Duration (ED) times 365 days per year. The Non-carcinogenic Intake Factor for eating would be:

$$\text{Non - carcinogenic Intake Factor (NIF)} = \frac{6.25\text{E} - 01\text{kg}}{70\text{kg} \times 9{,}125\text{days}} = 9.785\text{E} - 07 \frac{\text{kg}}{\text{kg - day}}$$

Note: In the above formulas, the units $\frac{\text{kg}}{\text{kg - day}}$ signify kilograms of the contaminated substance that the industrial worker ingests for each kilogram of his/her body weight per day. We have not canceled kilograms to emphasize that the kg in the numerator refers to the contaminated substance, but in the denominator kg refers to body weight.

**ACTIVITY 5:** Calculate **CIF** and **NIF** for drinking and breathing, and fill in the empty cells in Table 3.

**Table 3**

| Intake Factor | Reference Variable | Units | Value |
|---|---|---|---|
| Carcinogenic Intake Factor | CIF | | |
| • eating | | kg/kg-day | 3.495E-07 |
| • drinking | | | |
| • breathing | | | |
| Non-carcinogenic Intake Factor | NIF | | |
| • eating | | kg/kg-day | 9.785E-07 |
| • drinking | | | |
| • breathing | | | |

Our calculations so far have dealt with the contaminated substance – soil, air, or water. Now we can consider calculations involving the actual contaminants (hazardous materials).

## Risk Calculations

Risk calculations will depend on the type of contaminated substance (soil, air or water) as well as the type of hazardous material (carcinogenic or non-carcinogenic). The procedures for calculating the various risks are described in the following three sections.

### A. Ingestion of Soil

We will use the Intake Factors calculated in the last section to determine risk calculations. For carcinogens we will calculate Cancer Risk, and for non-carcinogens we will calculate the Hazard Quotient.

$$\text{Cancer Risk} = (\text{Chemical Concentration}) \times (\text{CIF}) \times (\text{Slope Factor})$$

$$\text{Hazard Quotient} = \frac{(\text{Chemical Concentration}) \times (\text{NIF})}{(\text{Reference Dose})}$$

The **Chemical Concentration** is dependent on the site which is under investigation. Water and soil samples are taken from the site and analyzed in a laboratory for chemicals of potential concern. In this case, we will use Chemical Concentration data from a land fill which was in heavy use at the Kennedy Space Center in the late 1960's and early 1970's.

In order to complete the Cancer Risk and Hazard Quotient calculations, we need some new quantities called a **Slope Factor** and a **Reference Dose**. Both these quantities give an indication of the health risk due to ingestion of a hazardous material. The Reference Dose is used to measure the effect of non-carcinogenic materials. Typical units for the Reference Dose are $\frac{\text{mg}}{\text{kg - day}}$. For example, the Reference Dose for thallium is 7.00E-05 $\frac{\text{mg}}{\text{kg - day}}$. This means that it is estimated that a person can withstand 7.00E-05 milligrams of thallium per kilogram of body weight each day without suffering ill effects. Thus, a person who weighs 70 kilograms can withstand about 0.0049 mg of thallium per day throughout a lifetime without an adverse effect.

The Slope Factor, used for carcinogenic materials, provides a different approach to the assessment of risk. The Slope Factor is a reasonable upper bound on the increased cancer risk from a lifetime exposure to a dose of 1 milligram of a carcinogen per kilogram of body weight per day. Thus, the units for the Slope Factor are 1/(mg/kg-day) which we can write as $\frac{\text{kg - day}}{\text{mg}}$.

Slope Factor and Reference Dose values for a particular substance are available from the Environmental Protection Agency (EPA).

| **Metal** | **Chemical Concentration** | **Slope Factor** | **Reference Dose** |
|---|---|---|---|
| Beryllium | 2.16E-01 mg/kg | 4.3E+00 kg-day/mg | 5.00E-03 mg/kg-day |
| Thallium | 7.13E+00 mg/kg | ---- | 7.00E-05 mg/kg-day |

Verify the following calculations for Cancer Risk and Hazard Quotient due to beryllium from ingesting soil at this site. Use the scientific notation display mode on your calculator.

$$\text{Cancer Risk} = (2.16\text{E}-01)\frac{\text{mg}}{\text{kg}} \times (3.495\text{E}-07)\frac{\text{kg}}{\text{kg - day}} \times (4.3\text{E}+00)\frac{\text{kg - day}}{\text{mg}} = 3.246\text{E}-07$$

$$\text{Hazard Quotient} = \frac{(2.16\text{E}-01)\frac{\text{mg}}{\text{kg}} \times (9.785\text{E}-07)\frac{\text{kg}}{\text{kg - day}}}{5.00\text{E}-03\frac{\text{mg}}{\text{kg - day}}} = 4.227\text{E}-05$$

Notice that all units cancel in both calculations. This means that Cancer Risk and Hazard Quotient do not have a unit label. This makes the comparison more straightforward.

**ACTIVITY 6:** Using the last equation as an example, compute the **Hazard Quotient** for thallium ingested at the site by eating soil, and enter the result in the appropriate cell of Table 4. (Thallium is not carcinogenic when ingested so there is no need to compute Cancer Risk.)

**Table 4 - Pathway Sums for Ingesting Soil**

| **Metal** | **Cancer Risk** | **Hazard Quotient** |
|---|---|---|
| Beryllium | 3.246E-07 | 4.227E-05 |
| Thallium | ---- | |
| **Pathway Sums** | | |

**ACTIVITY 7:** Add the values in the **Cancer Risk** and **Hazard Quotient** columns and enter the sums, called **Pathway Sums**, in the bottom row of Table 4.

## B. Inhalation of Airborne Soil

To calculate the Cancer Risk and Hazard Quotient for breathing contaminated air, we use the following formulas:

$$\text{Cancer Risk} = \frac{(\text{Chemical Concentration}) \times (\text{CIF}) \times (\text{Inhalation Risk})}{(\text{Volatilization Factor})}$$

$$\text{Hazard Quotient} = \frac{(\text{Chemical Concentration}) \times (\text{NIF})}{(\text{Volatilization Factor}) \times (\text{Reference Concentration})}$$

Table 5 summarizes the data necessary to calculate Cancer Risk and Hazard Quotient for inhalation of airborne soil. If a box contains dashed lines, this indicates that a value in this category is not relevant. For example, since there is no Reference Concentration indicated for cadmium, we do not calculate a Hazard Quotient for cadmium.

**Table 5**

| **Hazardous Material** | **Chemical Concentration in mg/kg** | **Inhalation Risk in kg-day/mg** | **Reference Concentration in mg/kg-day** | **Volatilization Factor in $m^3$/kg** |
|---|---|---|---|---|
| Beryllium | 2.16E-01 | 8.4E+00 | 5.00E-03 | 9.66E+08 |
| Cadmium | 8.66E-01 | 6.3E+00 | ---- | 4.63E+09 |
| Chromium | 1.57E+01 | 4.2E+01 | ---- | 4.63E+09 |
| 4-Methyl-2-Pentanone | 6.07E-04 | ---- | 2.3E-02 | 7.36E+03 |

**ACTIVITY 8:** Using the values given in Table 5 above and our previous calculations of **Cancer Risk** and **Hazard Quotient** as examples, fill in the appropriate cells of Table 6.

**Table 6 - Pathway Sums for Inhaling Airborne Soil**

| **Hazardous Material** | **Cancer Risk** | **Hazard Quotient** |
|---|---|---|
| Beryllium | | |
| Cadmium | | ---- |
| Chromium | | ---- |
| 4-Methyl-2-Pentanone | ---- | |
| **Pathway Sums** | | |

**ACTIVITY 9:** Referring to Table 6, add the values in the **Cancer Risk** and **Hazard Quotient** columns, and enter the sums in the last row labeled **Pathway Sums**

## C. Ingesting Water

To calculate the **Cancer Risk** and **Hazard Quotient** for drinking contaminated water, risk assessors use the following formulas:

$$\text{Cancer Risk} = (\text{Chemical Concentration}) \times (\text{CIF}) \times (\text{Slope Factor})$$

$$\text{Hazard Quotient} = \frac{(\text{Chemical Concentration}) \times (\text{NIF})}{(\text{Reference Dose})}$$

Table 7 summarizes the data necessary to carry out these calculations for the Hansom Landfill site. Again, if the box contains dashed lines, this indicates that the value in this category is not relevant.

**Table 7 - Hansom Landfill Groundwater Data**

| Hazardous Material | Chemical Concentration in mg/*l* | Reference Dose in mg/kg-day | Slope Factor in kg-day/mg |
|---|---|---|---|
| Arsenic | 3.92E-02 | 3.00E-04 | 1.50E+00 |
| Barium | 6.02E-02 | 7.00E-02 | ---- |
| Nickel | 7.29E-03 | 2.00E-02 | ---- |

**ACTIVITY 10:** Using the values given in Table 7 and our previous calculations of **Cancer Risk** and **Hazard Quotient** as examples, fill in the appropriate cells of Table 8.

**Table 8 - Pathway Sums for Ingesting Water**

| Hazardous Material | Cancer Risk | Hazard Quotient |
|---|---|---|
| Arsenic | | |
| Barium | ---- | |
| Nickel | ---- | |
| **Pathway Sums** | | |

**ACTIVITY 11:** Referring to Table 8, add the values in the **Cancer Risk** and **Hazard Quotient** columns and enter the sums in the last row labeled **Pathway Sums**.

Recall from ***Part 1: Risk Assessment 101***, that if the **Cancer Risk** is greater than $10^{-6}$ or if the **Hazard Quotient** is greater than 1, the contamination level at this site is considered dangerous at this site. According to EPA guidelines, some precautions are necessary or clean-up measures need to be taken.

**ACTIVITY 12:** Referring to the **Pathway Sums** determined in Table 4, Table 6, and Table 8, decide whether any of the **Intake Pathways** pose a risk to an **industrial worker** at the site.

## Writing a Report

Write a memo to your supervisor discussing the results of your risk assessment. This should include a recommendation regarding a remediation strategy. Keep in mind that your supervisor is trained in management and not risk assessment, so you will need to justify your recommendation.