# A CASE FOR CHANGING I-131 TRANSFER FACTORS BASED ON CHANGES IN DAIRY INDUSTRY PRACTICES

An Undergraduate Research Scholars Thesis

by

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# ABSTRACT

A Case for Changing I-131 Transfer Factors Based on Changes in Dairy Industry Practices.
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Following a large-scale radioactive release, transfer factors (TF) are used to estimate the amount of radioactive material retained by an organism. These values are based on the concentration of the consumed radionuclide and where it is deposited in the biological system. TFs exist for several radionuclides but special attention is paid to isotopes which might enter our food chain following a radiological event. Iodine-131 ($^{131}$I) is one of these radionuclides and if ingested by a cow, it will pass through the animal and concentrate in its milk. The milk can subsequently be ingested by humans, with infants being the sensitive pathway. TFs for the grass-cow-milk-infant pathway that are used to assess radiation doses to the public are based on research performed in the 1960s and 1970s. However, the dairy industry has changed drastically in the past 40 years. Dairy cows are now capable of producing more milk due to genetic advancements and administration of hormones. In fact, this increase in production is 5-fold: from 5,000 to nearly 25,000 lbs of milk per cow per year. By examining food intake and other production factors, a sensitivity analysis of the TFs was performed. This preliminary work indicates that TFs used to

calculate public dose may no longer be valid and may significantly overestimate potential doses to the public.

# ACKNOWLEDGMENTS

I would like to thank my advisor, Dr. Craig Marianno, for his guidance and confidence in my work.  I would also like to thank Eric Wagner for proposing this research topic and Dr. Andy Herring and Dr. Ellen Jordan for helping me understand past and current dairy industry practices.

# NOMENCLATURE

| | |
|---|---|
| $^{131}I$ | Iodine-131 |
| BST | Bovine somatotropin |
| DIL | Derived intervention level |
| DRL | Derived response level |
| FDA | Food and Drug Administration |
| FRMAC | Federal Radiological Monitoring and Assessment Center |
| HEDR | Hanford Environmental Dose Reconstruction project |
| NASS | National Agricultural Statistics Service |
| PAG | Protective action guide |
| TF | Transfer factor |
| TMI | Three Mile Island |
| USDA | U.S. Department of Agriculture |

# CHAPTER I

# INTRODUCTION

Iodine-131 ($^{131}$I) is a gaseous radioactive nuclide that is produced in fuel rods at nuclear power plants as a result of nuclear fission. During a reactor accident, $^{131}$I can be released in large quantities to the atmosphere and be dispersed for several hundred miles. Three major accidents have occurred in the history of nuclear power worldwide. The first accident occurred at Three Mile Island (TMI) Unit 2 near Middletown, Pennsylvania in 1979. As a result of a minor valve malfunction and operator error, the reactor core of TMI Unit 2 was partially melted. It is estimated that 18 Ci of iodine, mostly $^{131}$I, was released in gaseous form.[1] Experts have concluded that the amount of radiation released was too small to result in discernible health effects among the community surrounding TMI.[2] In 1986, a far greater accident occurred at Chernobyl in Russia. As a result of this accident, nearly 48,000,000 Ci of $^{131}$I was estimated to have been released.[3] The most recent nuclear power accident occurred in March 2011 at Fukushima Daiichi in Japan. The impact of radioactive releases as a result of this accident is to be determined.

During a radiological incident, beef, milk, and other food stuffs can be contaminated by the radiological release. Specifically, $^{131}$I will settle on grass and be eaten by livestock. The transfer of $^{131}$I from contaminated grass to cow milk is important because milk is a main component of the human diet, particularly in the U.S. Iodine-131 is a risk to humans if inhaled or ingested. This radioisotope selectively concentrates in the thyroid gland. If it is concentrated to a sufficient amount, it can cause thyroid cancer or other thyroid problems. The thyroid produces hormones that regulate the rate of metabolism, growth and function of the body.[4] Infants and children are particularly sensitive to intake of radioactive material such as $^{131}$I because of their rapid growth rates and large consumption of milk. For this reason, it is important to study the transfer of $^{131}$I along the grass-cow-milk-infant pathway.

A transfer factor (TF) is a value used to estimate the amount of radioactive material retained by an organism based on the concentration of the consumed radionuclide and where it is deposited in the biological system.[5] A TF is defined as the concentration of radionuclide per unit volume (Ci/L) divided by the concentration of the radionuclide per day (Ci/d). Most TFs are measured using experimental studies or biokinetic models of radionuclide uptake and retention. TFs are used to evaluate the impact of radioactive releases into the environment. Current TFs for the grass-cow-milk-infant pathway that are used to assess radiation doses to the public are based on research performed in the 1960s and as late as 1971. However, today's cows are fundamentally different than they were in the 1960s.

The milk yield of a cow has an influence upon the secretion rate of $^{131}$I into the milk.[6] Milk production in the U.S. has increased drastically over the past fifty years. In the 1960s, the average milk production was around 5,000 lb/cow/year. Today, the average milk production is nearly 20,000 lb/cow/year.[7] This significant increase is primarily due to genetic advancement in cows and could possibly have changed the way and/or rate $^{131}$I is processed, thereby affecting the TF. The aim of this research is to explore the accuracy of $^{131}$I TFs by further examining bovine biological models and TF calculation methods to determine whether or not currently used TFs need to be updated. If current TFs are inaccurate and are too conservative, milk could possibly be disposed of even though it is safe to consume, resulting in unnecessary fear and financial loss. On the other hand, current TFs could be inaccurate in that they are not conservative enough, and milk that exceeds current Food and Drug Administration (FDA) guidelines could be sold to and consumed by the public as a result.

# CHAPTER II

# METHODS

In August 2012, Eric Wagner, a scientist involved with radiological emergency response at the U.S. Department of Energy, raised the question of whether or not currently used $^{131}$I milk TFs are accurate. The objective of this research is to examine past efforts to calculate $^{131}$I milk TFs and apply them to current bovine biological models in an effort to determine to what extent these changes may affect published TFs.

The TFs currently used in radiological emergency response originate from the Hanford Environmental Dose Reconstruction project (HEDR). This project was created in an effort to estimate the dose received by individuals due to the release of radionuclides at the nuclear production facility known as the Hanford Site since 1944.[8] This document addresses the different environmental pathways that lead to human exposure to $^{131}$I. One of these pathways is the grass-cow-milk-infant pathway. The value for the $^{131}$I milk TF is defined using experimental data from 12 different sources. These sources date back to the 1970s and earlier. The calculation method for each of the 12 sources was studied. In addition, more recent journal articles relating to $^{131}$I TFs were examined to see if more recent calculations had been made and if the calculation methods had changed. The primary journals investigated were Health Physics and the Journal of Dairy Science.

Because cow biology used to obtain the HEDR TF values could have significantly changed since the 1970s, dairy industry experts were consulted for their opinion. Possible changes in TFs could be warranted due to the growth of the U.S. dairy industry through genetic advancements, industry innovations, and hormone treatments. A conversation with Dr. Ellen Jordan, Texas A&M University Dairy Specialist, confirmed that due to genetic advancement in dairy cows, U.S. milk production has increased from 5000 lbs/cow/yr to 20,000 lb/cow/year. This increase has caused cow dry matter intake and blood flow to increase. She suggested that introduction of new hormones has also affected liver function so much that the biology of a cow today does not compare to that of 50 years ago. Dr. Jordan suggested researching U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) for past and current U.S. milk production statistics and the Journal of Dairy Science for current information on cow biology. Research showed that the primary ingredient to increasing milk production is the use of bovine somatotropin (BST). This hormone's effect on cow biology was also further investigated in this work.

Using knowledge of the changes in the U.S. dairy industry over the past 50 years, a sensitivity analysis of existing TFs was performed. In their paper "Validity of the Term Transfer Coefficient," Ward and Johnson provide two methods used to calculated TFs for radionuclide concentration in milk, $F_m$.[9] The first method, detailed in Eq. (1), relies primarily on the intake of the radionuclide and its output in milk.

$$F_m\,(d/kg) = \frac{Milk\ Concentration\ (Bq/kg)}{Feed\ Conc.(Bq/kg)\ x\ \ Feed\ Intake\ (kg/d)} \tag{1}$$

When using Eq. (1) for sensitivity analysis, the feed concentration is kept constant. The components that will be allowed to vary are milk concentration and feed intake. Changes in these components based on recent dairy industry practices will help determine the need for $F_m$ to be updated.

Unlike the first method, the second method derives the TF on a physiological basis. This method is given in Eq. (2)

$$F_m\ (d/kg) = \frac{a}{kM} \tag{2}$$

where $a$ is the assimilation factor, $k$ is the effective biological rate constant (loss of radionuclide from milk) in $d^{-1}$, and $M$ is the amount of milk in the cow in kg. The physiological changes in dairy cows based on recent dairy industry practices will also help determine the need to update $F_m$.

# CHAPTER III

# PRELIMINARY RESEARCH RESULTS

In the 1960s and 1970s, much research was performed on the transfer of $^{131}$I to cow milk. These are still the primary sources for today's TF values. In nearly all of the experiments that serve as HEDR references, the dairy cows used for the studies were milked twice a day before feeding. Because dietary iodine intake is a main factor in determining TFs (see Eq. (1) ), the experiments also state the amount of feed the cows were allowed to consume. In 1960, Garner fed cows a "normal diet" of 30 lbs (13 kg) of hay and commercial dairy nuts divided into two equal feeds on a daily basis.[10] Later in the 1960s, dairy researcher Lengemann gave the cows 5-10 kg of commercial dairy feed twice a day that consisted of 18% protein and all of the mixed alfalfa hay the cows could consume.[6] There is no mention of pasture grazing as a means of feeding in any of the references, most likely because it is harder to control for an experiment. Many of the cows used in the experiments were Holsteins that weighed between 500 and 600 kg and produced 20 kg of milk per day.[11]

In the 1980s, the total amount of milk production in the U.S. skyrocketed. Figure 1 shows that annual milk production has grown from less than 120 billion pounds in 1970 to nearly 190 billion pounds in 2010. This is 63% growth. Figures 2 and 3 give a closer look at just the past decade. In the past 10 years, the industry has grown by 15%. While overall milk production has increased nearly by a factor of 2, milk production per cow has actually increased five-fold from 5000 lbs/cow/yr to 25,000 lb/cow/year. This is because there are about half as many cows now as there were in the 1960s.

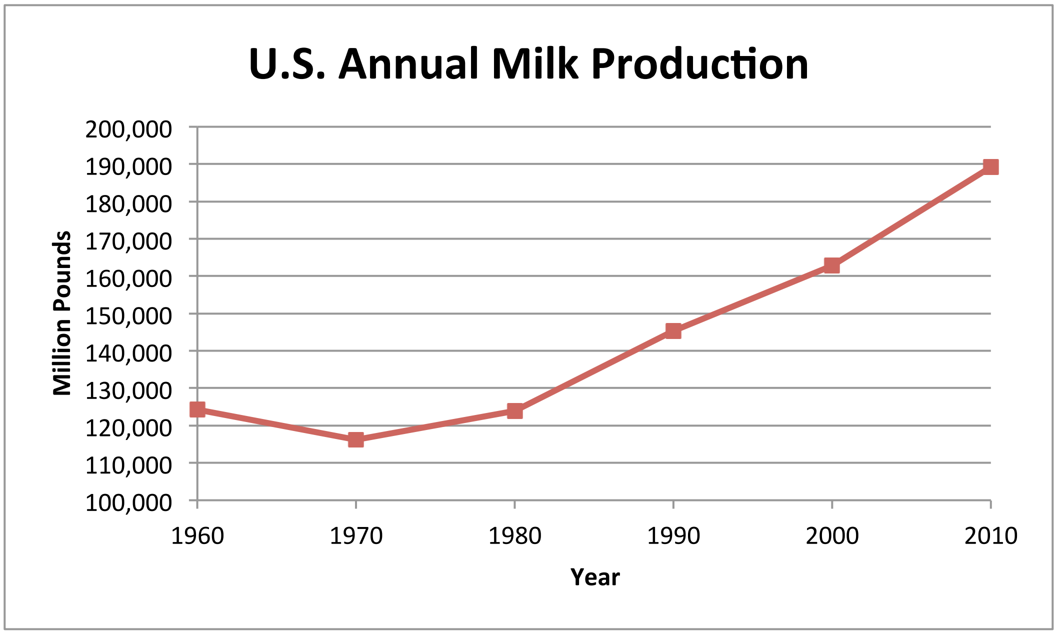

**Figure 1.** The U.S. dairy industry has grown 63% in the past fifty years. The data used to produce this graph are located in monthly milk production reports issued by the USDA NASS.

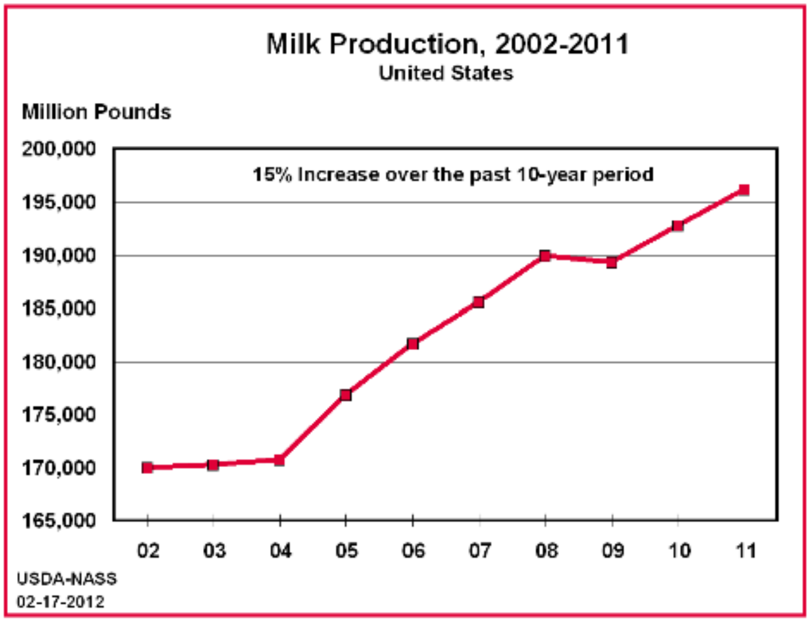

**Figure 2.** Annual milk production has grown by 10% in the past 10 years in the U.S. Source: USDA NASS

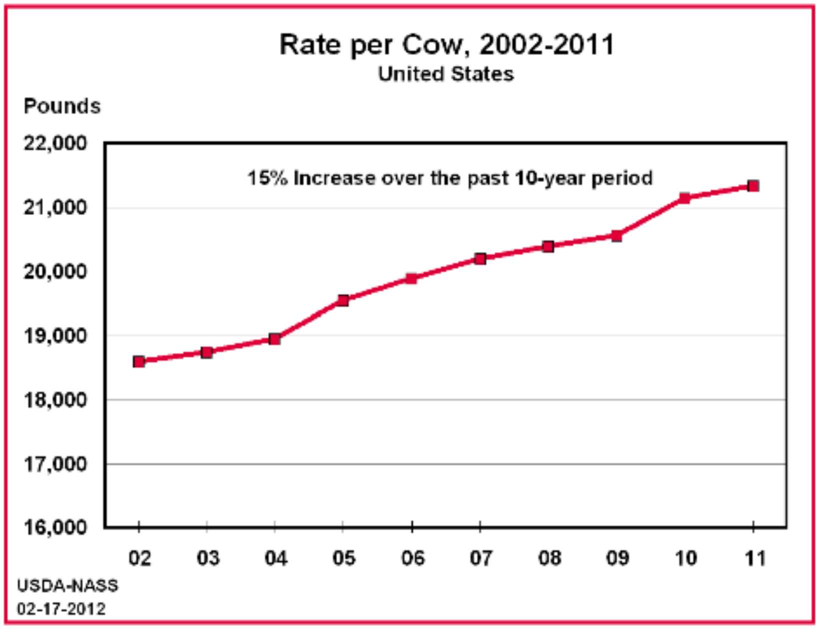

**Figure 3.** Annual milk production per cow has grown by 10% in the past 10 years in the U.S. Source: USDA NASS

Many factors account for this massive production increase. Among these factors are improved genetic selection, feeds, health care, and management techniques.[12] Of particular importance in the industry was the introduction of BST hormone in the 1980s. It was approved for use in industry by the FDA in 1993.[13] BST is a hormone that regulates metabolic processes within the cow. For calves, BST acts as a growth hormone. Once a cow is fully grown and lactating, BST helps allocate body fat for energy and diverts feed energy more toward milk production. Because of these physiological effects, 10-15% more milk can be obtained per cow that is treated with BST.[14]

Today, Holsteins account for over 90% of dairy cows in the U.S.[12] Increased dairy production has caused feed intake and dairy cow size to increase dramatically. In order to have the necessary nutrients for producing such large quantities of milk, cow feed intake has increased by at least a factor of 2.5. As a result, cow size has also increased from around 1200 lb to 1800 lb (roughly 800 kg). Milking frequency is now upwards of 3 times a day, depending on the facility and available labor. Of particular importance for radiological emergency response is the type of feed consumed by the cows and where it is stored. While in production (being milked), dairy cows eat a total mixed ration. This is a blend of silage, hay, and grain. Feed storage and milking location varies regionally. Some facilities are completely enclosed, while others are more of a shelter with open sides. During a radiological incident, dairies could be instructed to only feed their cows stored feed. If this stored feed is not completely enclosed, it could become contaminated. When the cows are not being milked, they graze in open pasture which is susceptible to contamination.[15]

# CHAPTER IV

# DISCUSSION AND CONCLUSION

Now that the changes in the dairy industry have been identified, how might TFs have changed? Equation 1 is used to examine the effects of milk concentration and feed intake changes on milk TFs. Feed intake has increased about 2.5 times due to increased milk production. Although dairy cows eat more stored feeds while in production rather than grazing in a pasture, these feeds are still at risk of being contaminated during a radiological incident because they are exposed to the air either while in storage or while being consumed (if consumed in an open shelter). Because milk yield has increased five-fold, concentration of $^{131}$I in milk is expected to decrease. By Eq. (1), this decrease in milk concentration combined with an increase in feed intake causes $F_m$ to decrease.

Equation 2 is used to examine the effects of a cow's physiology on milk TFs. Cow milk, $M$, has increased by a factor of 5. Increased milk production is only possible with an increase in metabolic rate. Therefore, the biological half-life of $^{131}$I is expected to decrease, causing $^{131}$I to move through the cow faster and the effective biological rate constant, $k$, to increase.[9] By Eq. (2), an increase in $k$ and $M$ will cause a decrease in $F_m$.

If TFs have indeed decreased as demonstrated by this sensitivity analysis, then the transfer of radioiodine to humans through cow milk is being overestimated. Decreased TFs have several implications on radiological emergency response. The Federal Radiological Monitoring and Assessment Center (FRMAC) is a federal asset that responds to radiological or nuclear incidents.

The U.S. Environmental Protection Agency, U.S. Nuclear Regulatory Commission, and U.S. Department of Energy created FRMAC in the early 1980s. FRMAC is responsible for issuing an assessment manual that is the primary tool used by response teams to interpret radiological measurements, predict doses to the public, and make recommendations regarding protective action.[16]

Section 3 of the 2012 FRMAC assessment manual defines response levels for several ingestion pathways. Of the methods listed, Method 3.3 defines the derived response levels (DRL) for radioactive material that is deposited in an animal's food for the milk pathway. The first ingestion DRL for milk is based on areal radioactivity on a grazing pasture, $Milk\_DRL_{area}$ (µCi/m$^2$). If a cow were to graze over an area with areal activity at the $Milk\_DRL_{area}$, the cow's milk would equal the derived intervention level (DIL) for the radionuclide of interest (in this case, $^{131}$I). The DIL is the concentration of a given radionuclide in food at which the ingestion dose to the most sensitive population and target organ has the potential to meet the ingestion protective action guideline (PAG). Equation (3) contains the $Milk\_DRL_{area}$ for a radionuclide $i$.

$$Milk\_DRL_{area,A,i} = \frac{DIL_{organ,age,i} * \rho_{milk}}{[\frac{(CRF * AFDIR)}{Y} + \frac{ASDIR}{\rho_{soil} * d_m}] * FDC_F * TF_{Milk,a,i} * e^{-\lambda_i t_m}} \tag{3}$$

A TF is present in Eq. (3). If this TF decreases, the DRL will increase. An increased DRL will reduce the area that is affected by the incident for emergency response purposes and therefore lower the milk embargo area.

The second ingestion DRL for milk is based on forage mass, $Milk\_DRL_{mass}$ (µCi/kg). If a cow were to consume feed with a concentration at the $Milk\_DRL_{mass}$, the cow's milk would equal the DIL. Equation (4) contains the $Milk\_DRL_{mass}$ for a radionuclide $i$.

$$Milk\_DRL_{mass,A,i} = \frac{DIL_{organ,age,i} * \rho_{milk}}{AFDIR * FDC_F * TF_{Milk,a,i} * e^{-\lambda_i t_m}} \tag{4}$$

A TF is present in Eq. (4). If this TF decreases, the DRL will increase. An increased DRL will increase the intervention level and decrease the need for milk embargo according to the PAG.

Transfer factors are also used to calculate the level of contamination in milk based on areal contamination of pasture and animal drinking water. Equation (5) contains the calculation for $C_{milk}$, the projected contamination level in milk (µCi/l).

$$C_{milk,i} = \left\{ Dp_{i,t0} * \left[ \frac{(CRF * AFDIR)}{Y} + \frac{ASDIR}{\rho_{soil} * d_m} \right] * FDC_F + [ADWIR * FDC_W * C_W] \right\} * TF_{Milk,a,i} * e^{-\lambda_i t_m} \tag{5}$$

As expected, if the TF decreases, the contamination level in milk will decrease. This in turn reduces dose estimates. Dose due to ingestion in mrem is calculated as given in Eq. (6).

$$E_{Ing,age} = \sum_{Subgroup} (DFIR_{subgroup,age} * FFC_{subgroup} * IngDP_{E,avg,age}) \tag{6}$$

$E_{Ing,age}$ is the committed effective dose from ingestion to the whole body. For each food subgroup, the daily food intake rate $(DFIR)$ in kg/d is multiplied by the fraction of food subgroup contaminated $(FFC)$ and the average ingestion dose parameter for the food group $(IngDP)$ in mrem*d/kg. The food subgroups are then summed. $IngDP$ is directly proportional to the projected contamination level, $C_{milk}$, of the food (milk). So as the contamination level in milk decreases, the committed effective dose from ingestion to the whole body will decrease.

In summary, TF values for $^{131}$I in cow milk could currently be overestimated. As a result, the dose to the public due to intake of contaminated cow milk could be overestimated. Inaccurate TFs could also cause unnecessary fear and financial loss due to disposal of milk (and possibly cows) that are below concerning levels of contamination. In light of massive changes to the dairy industry in the U.S. over the past 50 years, I recommend recalculation of $^{131}$I milk TFs.

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