FARAD PERSPECTIVE

Oil and petroleum product exposures to livestock

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Introduction

Concerns regarding potential environmental impacts from petroleum industry activities continue to fall under increased public scrutiny. Reports of contamination linked to accidental spills, leaks or other controversial topics such as hydraulic fracturing populate the news headlines with seeming regularity. Additionally, these reports are investigated and occasionally have scientific impact as well[1]. Of primary concern are the effects of the petroleum industry's activities on the environment and public health, a secondary concern that often fails to be recognized is the potential effect on our food supply through water and feed contamination resulting in chemical residues to be present in animal protein and milk. Additionally, topical exposures can affect other animal products such as hide and wool products.

Many of the activities of the petroleum industry take place in remote and often uninhabited (at least by humans) areas; additionally the harvested crude oil must travel by rail car, tractor-trailer, or pipeline to be further processed. These areas are often inhabited by the animals that provide the food that humans eat, in the form of livestock and wildlife. Some of the earliest reports on the impact of the oil industry to wildlife date back to the 1960's[2,3], and on farmed livestock in the 1970's[4,5]. Edwards has published numerous case-reports from the Oklahoma Animal Disease Diagnostic Laboratory regarding accidental exposure of livestock to oil field wastes and contaminants[6-10]. He was a pioneer in the field who recognized and reported on the unique concerns arising from the close proximity of livestock to oil and gas exploration, drilling, completion, production, transportation, and refining operations.

In 1957, McConnell noted that the "development of oil and gas resources in prime cattle lands and changes in technologies have brought unexpected hazards for which a precedent has not been established and toxicological information is not available"[11]. Unfortunately, despite the forward thinking of McConnell, Edwards, and others; this gap in knowledge is still quite large. To the authors' knowledge there are no reviews available that discuss the close association between the livestock and petroleum industries as it relates to food safety or tissue residue concerns. To that end, the objective of this review is a non-critical review of the literature and to summarize the current knowledge base (and knowledge gaps) in regard to the potential routes of exposure to livestock and the potential concern of residues contaminating our food supply after exposure.

Crude oil and its derivatives

Raw, naturally occurring liquid petroleum is often referred to as either petroleum oil or crude oil. Chemically, crude oil is a complex mixture of paraffinic, naphthenic, and aromatic hydrocarbons ranging in carbon number from C1 to > C60, in combination with smaller amounts of heteroatom compounds, metals, and hydrogen sulfide[12]. Crude oil can be further described by being termed sweet or sour according to its sulfur content; and heavy or light according to its API (American Petroleum Institute) gravity, which is an inverse measure of liquid petroleum's density relative to that of water. Further complicating the issue is the fact that crude oil is not a uniform substance and will vary in specific composition from oilfield to oilfield and can even vary within the same oil well at different points in time.

The steps involved in distilling and refining crude oil into the various end products (motor fuels, petroleum gases, gas oils, etc.) is well beyond the scope of this discussion and interested readers should find appropriate resources. However, suffice to say, the numerous steps from oil well exploration to drilling, pumping, and transporting the raw and final products represent many different processes where livestock can be exposed to these complex mixtures[7]. Additionally, abandoned oil and gas wells can serve as unattended areas for livestock and wildlife to explore and can serve as contamination sources to the animals and the environment. The active drilling sites and wells need to be properly fenced and maintained to ensure that material is not leaking from the wells or storage containers, otherwise livestock will have direct access to these contaminants, and their water and feedstuffs can also become a source of exposure through environmental contamination. Thousands of miles of pipe are strewn across remote areas and if not tended to and monitored regularly, these can be a source of exposure to livestock and wildlife as well. Again, abandoned pipelines are areas that are not maintained and can serve to expose animals, the environment, surface and ground water to contamination.

Hydraulic fracturing

Thousands of feet below the ground level within sedimentary rock (i.e. shale) there are large resources of "trapped" petroleum and natural gas. Hydraulic fracturing, or "fracking" as it is often termed, is a method to harvest these natural resources. Fracking itself is not a new endeavor for the petroleum industry, the first reported commercialized fracking was taking place by 1950[13]. However, within the last decade, due to technological advances in horizontal drilling and fracking, and the recent success in the Barnett Shale region, gas production from shale reserves has accelerated dramatically[14]. This rapid increase in fracking activity and its proximity moving closer to populated areas has led to an equally dramatic increase in public scrutiny over the potential impact on human health and the environment.

Generally speaking, the process of fracking involves the drilling of wells several thousand feet deep into the shale bedrock and then extending them horizontally. As can be seen in the cartoon illustration (Figure 1) the long horizontal wells can extended below areas of surface and subsurface water potentially contaminating these sources by vertical fracture. The next step is the actual fracturing procedure, whereby the L-shaped wells are pumped with millions of gallons of water, sand, and complex mixtures of chemical additives (0.5-2.0%) in order to fracture deeps beds of shale to release the trapped natural gas[13]. The additives to the water function for many different purposes, notably, the sand (termed proppant and the largest volume of additive to the fracking fluid ranging from 1 – 1.9% of the mixture) fills the tiny fractured areas and maintains an opening for release of the petroleum after the hydraulic pressure has been released[13].

Like conventional oil and gas operations, these wells have a surface casing that is inserted and cemented into place to protect groundwater[15]. The local regulations specify the depth below the freshwater aquifers that these casing must achieve. However, given the fact that the goal of fracking is to induce vertical fractures in the bedrock, there is the potential for these fractures to spread upwards such that sources of water could become contaminated. Unlike conventional oil drilling operations, hydraulic fracking involves large volumes of fluids, which increase chances of accidental spillage. In addition, fracking fluids contain complex mixtures of additives that are considered proprietary and thus, comprehensive lists of chemical additives are unavailable. Several incomplete lists of chemical additives in fracking fluids have been compiled (see www.fracfocus.org) and reveal the presence of more than 600 chemical additives in these complex fluid mixtures[16]. These lists generally include

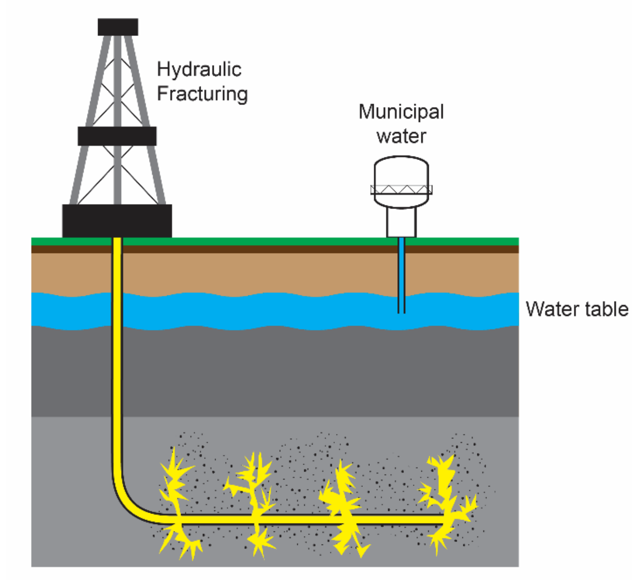

Figure 1 – Cartoon illustration (not to scale) depicting the general concept of hydraulic fracturing.

potassium chloride, acids, various organic and inorganic gels, biocides, clay stabilizers, corrosion inhibitors, foamers and defoamers used at different stages of production, friction reducers, scale controllers, and surfactants[16,17]. Table 1 is a non-exhaustive list of a few of the chemicals that are commonly found in fracking fluids.

Table 1 also includes LogP (logarithm of the octanol/water partition coefficient) values for each compound. LogP values were obtained from an online resource (www.chemspider.com). LogP provides one measure of a molecule's relative lipophilicity, which is an important determinant of the compound's capacity to partition into lipid rich environments such as biological membranes, which can markedly impact pharmacokinetic measures including bioavailability and, metabolism as well as the potential for accumulation and toxicity. These values are also used to determine environmental persistence. In general, the higher the value of LogP, the more lipophilic the molecule is, implying that higher logP values stand a greater risk for transcutaneous or mucus membrane absorption. Other molecular properties including molecular weight and relative water solubility are also important.

As noted by other researchers, specific physical chemical information is difficult to find on many chemicals used in fracking due to incomplete information on the chemicals used, insufficient information contained in material safety data sheets (MSDS), the presence of many synonyms for the chemicals used, and not providing a Chemical Abstract Service number which would foster more complete identification[16]. Finally, many of these compounds are complex mixtures which makes a complete risk assessment difficult.

Chemical Name	CAS	LogP
1,1-hexanediamine	000124-09-4	0.27
1,2, 4-trimethylbenzene	**000526-73-8**	**3.63**
1-hexanol	000111-27-3	1.82
2,2-dibromo-3-nitrilopropionamide	**010222-01-2**	**1.01**
2-butoxyethanol	000111-76-2	0.57
Acetaldehyde	**000075-07-0**	**-0.17**
Acetic acid	000064-19-7	0.09
Acrolein	**000107-02-8**	**0.19**
Boric acid	001333-73-9	-0.22
Citric acid	**000077-92-9**	**-1.67**
Diethylenetriamine	000111-40-0	-2.13
Ethylene glycol	**000107-21-1**	**-1.20**
Ethylene glycol monobutyl ether	000111-76-2	0.57
Formaldehyde	**000050-00-0**	**0.35**
Formic acid	000064-18-6	-0.46
Glutaraldehyde	**000111-30-8**	**-0.18**
Hydrochloric acid	007647-01-0	0.54
Isopropanol	**000067-63-0**	**0.28**
Lauryl sulfate	000151-21-3	2.42
Methanol	**000067-56-1**	**-0.63**
Naphthalene	000091-20-3	3.17
Radium (ra-226)	**007440-14-4**	**0.23**
Strontium	007440-24-6	0.23
Thioglycolic acid	**000068-11-1**	**0.03**

Table 1 – Non-exhaustive list of chemicals reported to be used in fracking fluids. Sources for this table include Spellman (2013), Colborn et al. (2011), www.fracfocus.org, and www.chemspider.com. CAS = chemical abstract number, LogP = partition coefficient in octanol-water

Fracking activities offer many of the same potential interactions with livestock as mentioned previously. The fracking sites are often in the same remote areas and require transportation of the chemicals to and from the site. Additionally, following the high pressure pumping of the liquid mixture into the well, the flow back fluid is recovered and placed in holding ponds or sealed tanks for reuse [17]. This flow back fluid can contain raw petroleum hydrocarbons, minerals, heavy metals, and radioactive nuclides (e.g. strontium and radium) that are released from these fracking sites[18]. Further, as pointed out by Bamberger and Oswald (2014), there might be an even greater concern with the substances released from deep within the shale and changes in the chemical composition of the drilling fluids due to chemical reactions occurring at very high temperatures within the well between subterranean mineral, gas and fracking-additive constituents[19]. Case reports of human and animal exposure to some of these fluids have been documented, but, due to incomplete testing and chemical disclosures, as well as legal nondisclosure agreements; these reports are anecdotal[20]. However, they do raise concerns to the potential risk of exposure to animals and our food supply.

Reviewing the literature

Case reports

In a study of the impacts of gas drilling on human and animal health, Bamberger and Oswald (2012) interviewed animal owners and their veterinarians in six different states who had reportedly been affected by accidental exposures to either conventional wells (shallow or deep vertical wells) or fracking wells (horizontal wells)[20]. They investigated 24 separate cases involving both human and animal exposures to these operations. The two most notable food animal exposures involved a case in Louisiana where 17 cows died with one hour post exposure, and in Pennsylvania where 70 cows died after exposure[20,21].

In the Louisiana incident, a petroleum worker allegedly shut down a chemical blender during the fracturing process, which resulted in the release of fracking fluids into an adjacent cow pasture resulting in the death of 17 cows within one hour of exposure[20]. The final necropsy report, released from the veterinarian with owner consent, detailed the most likely cause of death as respiratory failure with circulatory collapse, which mirrors pathological findings reported previously from quaternary ammonium compound exposure[22].

In Pennsylvania, as reported by the owner, 140 cows were exposed to fracking wastewater when the liner of a wastewater impoundment was allegedly slit and drained into a pond used by the cattle for a water source[18]. Seventy of the 140 cows died and the remaining cows reportedly had a high incidence of stillborn and stunted calves. Bamberger and Oswald reported, that in this case, there was a natural control group of 60 cows owned by the farmer in another pasture not having access to the same water source that showed no health or growth problems. As the authors suggest, this is a close approximation to a controlled experiment that lends a strong implication to wastewater exposure in the death, failure to breed, and reduced growth rate of cattle. To minimize such waste containment leakages occurring from fragile storage liners, the industry has recently used solid metal tanks for storing fracking waste.

Aside from the report by Bamberger and Oswald, the overwhelming majority of literature available on the interaction of livestock with the petroleum industry are clinically based case reports and investigations into accidental exposures. It has been noted that livestock will ingest crude oil and other petroleum products when they are suffering from dehydration, lack of clean water sources, fed poor quality or contaminated feedstuffs, seeking salt, or perhaps even just from curiosity[6,7,23,24]. It has been reported that cows on a balanced diet with water, ad libitum, will ingest crude petroleum, suspected to arise from curiosity alone[25].

Unusual exposures noted in case reports have varied from cattle directly drinking diesel fuel flowing from a storage tank, from puddles of oil near a tank battery, from slush pits of volatile petroleum and petroleum distillates, from pipeline breaks, from water contaminated with aviation turbine fuel or from various transportation leaks due to overturned trucks, rail car tanks, and tanker ship disasters[23]. The best and most comprehensive available review of the clinical and toxicological hazards of oilfield pollutants was published in 1997 by the Alberta Research Council[26]. A condensed and more recent review source of the petroleum industry and its toxicological significance to livestock and wildlife can be found in a chapter written by Coppock and Christian (2012)[15].

The clinical effects vary depending on the type of exposure (i.e. aerosolized inhalation, ingestion, or dermal contact), the chemical composition of the substance, and the relative dose of the exposure. Clinical signs can vary from no observed effects to sudden death. Generally speaking, case reports demonstrate signs of neurotoxicity (hypoesthesia, hyperesthesia, mydriasis, head tremors, ataxia, seizures, etc.), depression, ptyalism, epiphora, hypo- or hyperthermia, and generalized gastrointestinal symptoms (emesis, bloat, rumen stasis, abomasal displacement, loose or hard feces, etc.)[26,27]. Based on the detrimental health effects associated with exposures to petroleum-derived products, it is readily apparent that food products from animals with clinical signs of petroleum toxicity should not be allowed to enter the human food chain.

Dermal exposure

Given the fact that humans are often exposed to these same pollutants by working in and around the petroleum industry or its products; the area of transdermal absorption has received a significant amount of scientific attention. One such area is the transdermal absorption of jet fuels by workers in the commercial and military airfield setting, of which a few of the publications will be briefly reviewed here. The fuels that are the subject of these investigations most typically involve the military jet fuels JP-8 and JP-8(100), and the civilian aircraft equivalent Jet-A. These fuels, similar to diesel fuel, are a complex mixture of aromatic and aliphatic hydrocarbons most aptly described by their carbon backbones (C9 – C16) and boiling range (302 - 554˚F)[28,29]. Due to the chemical complexity of these compounds containing many performance enhancing additives and stabilizing components, it is nearly impossible to assess the absorption of all of the fuel constituents and one must instead analyze "marker components" in these fuels including components such as naphthalene, hexadecane, and dodecane[29]. Naphthalene is a low molecular weight aromatic compound whereas hexadecane and dodecane are less volatile and represent the long-chain aliphatic hydrocarbons fuel constituents.

Utilizing radiolabeled naphthalene, hexadecane, and dodecane applied simultaneously, non-occluded, to isolated perfused porcine skin flaps, Riviere *et al.*(1999) demonstrated that overall, the percutaneous absorption was relatively low with the greatest estimated penetration being only 1.5% of the applied dose[29]. Pig skin was used since it is an accepted model for chemical absorption across human skin. However, naphthalene was rapidly absorbed with a minimal propensity to stay in the skin and a tendency to partition into subcutaneous fat after absorption. Compared to the aromatic fractions, both dodecane and hexadecane had significantly higher residence times in the skin with less systemic absorption but effectively, resulting in a prolonged exposure time.

Studying the effects of performance additives (DiEGME, 8Q21, and Stadis450) on the dermal disposition of marker components in Jet-A, Baynes *et al.* found that various combinations of these additives could alter penetration of naphthalene, hexadecane, and dodecane into the skin and fat tissues[30]. In follow up studies, Muhammad *et al.* reported that performance additives MDA was a significant antagonist of both naphthalene and dodecane absorption while another additive BHT was a potent absorption enhancer of naphthalene[31]. Although these studies were conducted in porcine models for human risk assessment extrapolations, they are obviously directly relevant to dermal exposures to pigs, as might occur from diesel fuel spills seen in flooding such as occurs after hurricane damage to swine production units.

Similar studies in ruminant skin have not been performed to the authors' knowledge, but due to anatomical differences, one could infer that the chemical uptake in ruminant skin may be greater than across pig skin since ruminant epidermis is thinner than that of a pig[32]. Flux of topically applied abamectin was greater than or comparable in calf compared to porcine skin across formulation[33]. Results from an unpublished study with various pesticide agents indicate that agents exhibit up to three-fold greater rates of flux in isolated calf skin relative to porcine skin in vitro (Riviere, personal communication). Data from the studies referenced above, utilizing pig epidermis, could provide an initial lower-bound estimate of the fate of topical exposure to hydrocarbons in ruminants.

Carcinogenicity

References can be found in the veterinary literature of crude oil and petroleum products containing compounds suspected of being human carcinogens[6,27]. Additionally, one author pointed to the possibility of rumen microflora metabolizing chemicals found in crude oil or petroleum products to form carcinogenic metabolites[27], however, detailed citations were not provided.

Skin tumors have been observed in two-year carcinogenicity studies in mice with Jet-A, however the degree of skin irritation was correlated to the prevalence of tumors[34,35]. In-depth reviews of the carcinogenic effect of middle distillates fuels (kerosene, aviation fuels, no. 1 fuel oil, and diesel fuel) in laboratory animal studies have found the carcinogenic effect to be nongenotoxic but rather due to chronic skin irritation and injury with repeated exposures of the mixtures to the skin[36,37].

Given these facts, McDougal *et al.* surmised that skin tumors caused by occupational exposures to JP-8 are not likely for two reasons: 1) the chronic repeated application of jet fuel to the skin is required to cause severe irritation and tumors in rodent studies. This is not a realistic scenario for human exposures, because workers would undoubtedly limit exposures to avoid the repeated irritation; 2) the production specification that limits the sulfur content to less than 0.3% would reduce the tumorigenicity of JP-8 if prolonged exposure occurred.

Although not completely equivalent, it would seem livestock would fall in the same category of miniscule risk of either developing tumors or passing this tumorigenicity through residues of these chemical mixtures in their meat and milk. For example, given a short-term accidental spillage exposure scenario, it would seem that the exposure would be acute in nature allowing residues to be cleared from the animal, or the exposure would be so high as to cause death or severe clinical illness such that the animal would not enter the food chain. In the unlikely event of chronic exposure, accumulation could potentially occur although toxicological sequelae would most likely prevent such exposure and thus marketing of exposed animals.

Residue studies

Only one article was found that studied the distribution and elimination of any of the components of crude oil in food animal species. In 1985, Eisele studied naphthalene distribution in the tissues of laying pullets, swine, and dairy cattle[38]. In this study animals were dosed with ^{14}C-naphthalene orally as either a single dosage or a chronic exposure of 31 days (Table 2). Three swine, three pullets and one cow were sacrificed at one and three days post-exposure for the acute experiment. In the chronic experiment, three swine, pullets and one cow were fed the labeled naphthalene for 31 days and sacrificed the next day for tissue concentration analysis.

Single Dose Study			**Chronic (31 days) Dose Study**		
Species	N	Dose (mg)	Species	N	Dose (mg)
Chicken	**6**	**0.443**	**Chicken**	**6**	**0.036**
Swine	6	2.46	Swine	6	0.112
Dairy cow	**1**	**30.69**	**Dairy cow**	**1**	**5.115**

Table 2 – The number of animals used and dosage administered by mouth, to each species in a study of the distribution of naphthalene distribution in tissues of laying pullets, swine and dairy cattle[38].

The residue analysis findings for all three species can be found in Table 3. In the laying pullets, after both the acute and chronic exposures, naphthalene was taken up by all the major tissues. This is consistent with the topical skin exposure studies cited earlier. The kidney was the major site of naphthalene depot formation followed by adipose, lung and liver. Naphthalene was also found in the muscle but seemed to concentrate slightly more in the “dark meat”. They demonstrated that naphthalene was taken up by the eggs within 24 hours and residues persisted beyond 72 hours in both the acute and chronic studies.

In swine, the major site of deposition was in the fat but naphthalene was also present in muscle and persisted beyond 72 hours in this study. In the chronic study, the lung, liver, and heart were the major organs of naphthalene deposition. They found that the concentration of the naphthalene increased in the liver from 24 to 72 hours, suggesting bioaccumulation.

Finally, in the single dairy cow studied, the liver was one of the major tissues for naphthalene deposition. There appeared to be differences in the distribution of naphthalene to different muscle groups, and naphthalene was found in the milk within eight hours of the acute exposure. In the chronic study they demonstrated that the clearance of naphthalene from the milk was rapid during the three days in between the last exposure and the sampling at slaughter.

In summary, these investigators found that naphthalene seemed to preferentially concentrate in the kidney in pullets, the fat in swine, and in the liver in the dairy cow, with the compound also found in the eggs of the pullets and in the milk of the dairy cow, suggesting that such exposures do present potential residue concerns.

FARAD experience

FARAD has been involved in several cases where animals have been directly exposed to crude oil, its refined products, and one case of a herd exposed to water containing fracking wastes. We have been presented cases where mass exposures have been the result of fuel spills due to natural disasters such as flooding after costal hurricanes.

Each case is unique and there is most certainly not enough data to make general withdrawal recommendations, since as has been presented here, the chemicals of exposure can vary widely and are often not known unless a sample can be taken of the material of concern. These cases are complex and often take much time for

Chicken

	Acute 24 hr		Acute 72 hr		Chronic 72 hr	
Tissue	**Mean**	**±SE**	**Mean**	**±SE**	**Mean**	**±SE**
Liver	8.75	0.39	0.96	0.12	0.74	0.10
Fat	13.50	2.00	1.60	0.06	0.37	0.11
Dark meat	2.63	0.26	0.64	0.21	0.33	0.04
White meat	1.68	0.16	0.30	0.03	0.16	0.01
Heart	3.91	0.39	0.43	0.03	0.44	0.06
Spleen	3.76*	-	1.36*	-	0.71*	-
Kidneys	42.90	1.05	8.03	1.07	2.40	0.22
Lungs	13.50*	-	2.93*	-	1.24*	-

Swine

	Acute 24 hr		Acute 72 hr		Chronic 72 hr	
Tissue	**Mean**	**±SE**	**Mean**	**±SE**	**Mean**	**±SE**
Liver	0.26	0.06	0.34	0.24	0.11	0.05
Fat	3.48	2.16	2.18	0.16	0.03	0.01
Loin	0.11	0.03	0.05	0.00	0.05	0.00
Ham	0.12	0.02	0.06	0.00	0.06	0.00
Heart	0.09	0.04	0.05	0.00	0.11	0.03
Spleen	0.07	0.01	0.06	0.02	0.09	0.05
Kidneys	0.96*	-	0.26*	-	0.09*	-
Lungs	0.16*	-	0.26*	-	0.15*	-

Dairy Cow

	Acute 72 hr	Chronic 72 hr
Tissue	**Mean**	**Mean**
Liver	0.015	0.006
Fat	0.001	0.001
Loin	0.008	0.003
Flank	0.016	0.002
Heart	0.01	0.004
Spleen	0.01	0.004
Kidneys	0.01	0.002
Lungs	0.012	0.003

Table 3 – Distribution of naphthalene or metabolic by products in tissue of laying pullets, swine, and a dairy cow. All data are % total dose / g tissue 10-3 (dose is reported in Table 1). * = one sample[38]

FARAD responders to accumulate, analyze, and interpret the very limited data that is available in the literature and from private sources. However, FARAD has been able to draw conclusions that sometimes allow the producer to eventually market the animal, thereby not incurring further financial loses, while allowing for continued safety of our food supply.

Conclusions

There is little data in the absorption, distribution, and elimination of the chemicals contained in crude oil in livestock species. Generally speaking, studies have shown that aromatic hydrocarbons are absorbed dermally and become systemic more so than aliphatic hydrocarbons, while less volatile aliphatic chemicals can remain in the skin longer, forming a depot of chemical. It would stand to reason that the sooner a dermal exposure is recognized and the hide of the animals is washed, preventing further absorption, the sooner the chemical can be eliminated from its system. Acute dermal exposures seem to be of very little risk to both the animal and to the human consumer, but this point certainly needs much further study to assess impact on tissue residues.

The area of livestock exposure to fracking by-products has further uncertainty as it relates to the potential exposure to hundreds of unknown chemicals. There is a tremendous amount of work that needs to be done in this area to begin to even understand what types of risks this presents the food supply from a residue standpoint. The first point that needs addressing, from a human health aspect too, is a greater understanding and clarity of the full composition of the products contained in the fluid that is pumped into these fracking sites and removed after harvest of petroleum product. Perhaps of even more concern is the wastewater resulting from the fracking fluid; which may contain heavy metals, radioactive isotopes, and many unknown chemical complexes as a result of the chemical interactions taking place under the very high temperature and pressures underground. This includes livestock exposure to persistent and potentially hazardous radioisotopes such as radium and strontium. These elements are persistent within the environment and the body and strontium can be found in older adults at measurable amounts[39]. There are many unanswered questions that need to be addressed before we can begin to make attempts at putting this into perspective in regards to the risk to our food supply from fracking.

There is sparse data available concerning the food safety aspect of livestock sharing their environment with the petroleum industry. All the while considering the complexity of crude oil, a great deal of research needs to address this area to further characterize the potential human risk from consuming meat, milk, and eggs from animals that have been exposed to crude oil or its end products. When such exposure occurs, the first step should always be to terminate exposure, remove contaminants form the hide if it is a topical spill, and carefully observe animals for adverse signs. Since the potential to produce violative residues in edible tissues is a function of variable factors such as dose, length of exposure, animal age, time to market, etc.; no simple recommendation on appropriate withdrawal times can be made.

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