Cattle and the Petroleum Industry: An Introduction for the Veterinarian

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Background

Veterinarians are occasionally called upon to investigate concerns from cattle producers who feel they have suffered economic losses resulting from the effects of industrial activity on the health and productivity of their livestock operation. The following is an introduction to some of the problems that can occasionally result from the close proximity of cattle to petrochemical activities. Some strategies for investigating these types of problems are also suggested. Peer-reviewed experimental or observational field studies of the effects of the petroleum industry on livestock are very limited. The available literature consists of scattered case reports, reviews of these case reports, a few small experimental dosing studies in cattle, experimental results extrapolated from other species, and observational reports from the "gray literature" of conference proceedings and environmental accidents or complaint investigations.

This paper is intended as a brief introduction for the practicing veterinarian called to investigate petroleum related complaints. It is not intended to be an exhaustive review of the available material. A more detailed presentation of the potential hazards to livestock from the oil and gas industry has recently been released by the Alberta Cattle Commission.[1]

Oil and gas production and processing facilities are located throughout many of the prime cattle producing areas in Canada and the United States. The extent of problems resulting from the interaction between the cattle and petroleum industries has not been documented. An attempt to quantify the extent of the problem would be limited in most regions by the lack of a mandatory centralized reporting system. Concerns from livestock producers may not be reported. Complaints, if reported, might be made to the local veterinarian, to the petroleum company, or to one of several government agencies involved in the reporting or investigation of concerns. There has been no central investigation coordinator or formal reporting procedure for these concerns which would permit the actual extent of the perceived problem to be measured.

In 1992, the Alberta Cattle Commission attempted a survey of its members (Alberta Cattleman, Vol. XVI, No. 4, July 92). The response rate was very poor. Of the 40,000 survey forms mailed out, only 250 had been returned by the third week of December, 1992. Of the 250 respondents, 64% had some sort of dispute with the petrochemical industry and 70% of those arguments were still unresolved. Complaints included: increased public access to private land, gates left open, escaping livestock, trespassers, littering, and noxious weed infestations. Soil contamination, and effects on quantity and quality of water were noted by 45% of respondents. Of the respondents, 33% reported health problems in their livestock related to ingestion of toxic compounds from contaminated soil, water, and air.[2]

Potential Sources of Exposure to Cattle

Oil field installations often are located in areas used by livestock for grazing. Commonly encountered installations include crude oil wells, natural gas wells, tank batteries, pipelines, compressor stations, and processing plants. There are several potential hazards to livestock allowed to access oil field sites. These hazards have been summarized into five categories: chemicals used in all phases of well site production, heavy metals in lubricants and well additives, salt water pumped from the reservoir with crude oil and separated at the surface, mechanical injury from well site equipment, and petroleum products and process emissions.[3]

The tendency of cattle to voluntarily ingest petroleum products has been documented by several authors. Factors which may increase the intake of petroleum products by cattle include thirst when water is not readily available, contamination of usual food and water supplies, desire for salt, or when pasture quality is poor.[4-7] Cattle can, however, lick and ingest crude oil even when water and feed are available.[8] Curiosity, especially in young animals, may explain voluntary ingestion of oil and gas. Contaminated chemical packaging and contaminated protective work clothing has also been reported to be consumed by cattle.[4]

Potential hazards to cattle can exist in most energy production activities.[4] Hazards during exploration have included explosives, discarded chemicals, and traumatic injury from shot holes. The processes of drilling and completion have provided opportunity for exposure to petroleum hydrocarbons, drilling muds, salt water, caustic chemicals, and possibly heavy metals. During production at well sites livestock have been exposed to crude oil and condensates, salt water, heavy metals, caustic chemicals, solvents, trauma from pump jack and other equipment, and electrocution. Accidents during transportation by pipeline or truck have also resulted in exposure of livestock to crude oil, natural gas, condensate, salt water, caustic chemicals, and other various toxic wastes.

Many of these potential problems have been successfully avoided by good industry practice on lease sites, good fences, and good communication between the land owner and oil company. Improvements in industry practice and regulations have decreased the probability of occurrence for many of these hazards. For example, the use of explosives in exploration has declined with the advent of new vibratory equipment in seismic surveys.[1]

The greatest hazard for livestock may exist during the drilling and production phases. Blowouts, or uncontrolled releases of fluids from a well, have been reported during drilling operations. Other risks include the possibility of traumatic injuries. Drilling muds are circulated into the bore hole to remove cuttings, lubricate the drilling bit, and provide hydrostatic pressure to prevent the well from blowing out. A variety of potentially toxic chemicals are added to the drilling mud to maintain essential physical and chemical properties and to control bacteria, corrosion, and scale formation.[4] Because of increased environmental awareness by the energy industry and regulatory agencies, the use of many potentially harmful compounds including lead in "pipe dope" and chromium have been phased out during the past five to ten years.[1]

Drilling muds may contain a wide variety of compounds that vary based on the type of mud used. Freshwater based gel-chem mud systems are the most commonly used in Alberta. Oil-based muds (often diesel based) and salt muds (sodium or potassium chloride muds) are used less commonly. The drilling fluids may be stored in on-site sumps (earthen pits) that may pose a hazard to cattle if they contaminate ground water supplies, overflow or are not adequately fenced. The chemicals of greatest potential concern are dissolved metals, hydrocarbons, and salts.[1] Chemical residues in empty containers left accessible to curious cattle can also create a hazard.[4]

Fracturing the oil-bearing formations may be required to allow the oil and gas to be recovered from the well. This process is referred to as "fracking" and can be completed by "acidizing" the well, explosive fracturing, and hydraulic fracturing.[4] "Acidizing" of gas wells has occasionally been raised as a potential problem by some livestock operators concerned about the fate of this chemical mix when it is produced back from the well. Gas wells may be produced directly to atmosphere (flared) during completion in order to collect samples of the gas for analysis and to remove debris and production chemicals prior to building a pipeline or allowing the contents into available lines. Similar processes are often used in well maintenance or workover operations to increase production. Spillage or release of chemical used in these processes can result in ingestion by livestock or odor concerns.

A petroleum salt water emulsion is pumped from the well to a nearby tank battery, where the water is separated from the sediment and oil. The produced water which is often high in salt content can be held in tanks until it is transported by truck or pipeline to a disposal well. The oil is held in storage tanks until it can be moved to a refinery. Tanks may overflow or lines may break, contaminating feed and water supplies and allowing livestock direct access to pools of oil or salt water.[4] Salt toxicity has not been recognized as a significant problem in Canada.[3] The produced fluids from some wells can be greater than 95% brine or salt water. Disposal of salt water can be accomplished in evaporating ponds leaving salt residues. Flooding of slush pits and evaporation ponds can potentially result in contamination of fresh water supplies.[9]

Flare stacks are found on well and processing sites. These flares are very visible and are a source of concern to some cattle producers. Flaring is necessary vent for the gas in emergencies where the processing plant is shut down or there is a problem with the pipeline or compressor station. Controlled ignition of the gas by the flare stacks is necessary to decrease the potential toxicity of constituents such as hydrogen sulfide and prevent accidental ignition or explosion of raw gas. Incomplete combustion is a potential problem in these flares that have widely variable combustion efficiencies. The ground level concentration of these products in the emissions and resulting risk to livestock is difficult to measure because of variation in the dispersion patterns and their chemical instability. Flame outages may result in the release of raw gas.[1]

Numerous pipelines used for transportation of crude oil, water, and natural gas crisscross the countryside. Pipeline leaks and ruptures have been amongst the most common concerns investigated by this author. Pipeline breaks in remote areas may go undetected for some time.[4] Breaks in pipelines crossing streams and rivers can be particularly hard to contain. The winter months may increase the hazard to livestock as other sources of drinking water might be frozen. Livestock can also crack open valves on equipment and storage tanks by congregating around and rubbing on storage facilities in cold weather.[4]

Compressor stations may be necessary in large gas collection systems to improve efficiency of gas movement through the pipelines to the central processing facility. Condensate (or the liquid phase of the gas) may be removed in separator tanks at the compressor station. Raw gas can be released through errors in regulation of these tanks. Raw or processed gas may be flared from the compressor station during periods of mechanical difficulty at the processing plant.

Natural gas processing facilities are often located in rural areas in the midst of cattle populations. The operations and emissions from these facilities are highly regulated particularly for those that produce sour gas. Operational upsets do occasionally occur, however. Sour gas is natural gas containing hydrogen sulfide. Flaring of raw gas at processing plants can result in odor complaints as combustion is less efficient than that occurring in the main incinerator stacks during normal operations. Occasional accidental releases and fugitive emissions from valves and connections can also be a localized near or on site concern.

Disruptions in pasture quality caused by pipeline construction are some of the most frequent complaints from livestock producers. Animals hit by trucks while checking lease sites or during transportation of oil or waste materials is another frequent, but usually readily resolved issue.

Noise from exploration (seismic operations), well drilling and completion (flaring), and normal operations of compressor and processing facilities is occasionally reported as a concern by livestock owners. One herd in close proximity to a natural gas line explosion reported cattle off feed for several days following the pipeline break. Cattle did not go back on full feed until activity related to investigation and cleanup decreased (helicopters overhead and increased heavy truck traffic).[10]

The effect of noise related stress in cattle has not been well defined. Average daily gain was studied in lambs exposed to different types and levels of sound. A significant difference in performance was found based on both sound type and intensity. Acclimatization to sound was reported in this study.[11] Auditory stimulation has been shown to interfere with fertility in rats.[12] Noise induced stress in male mice produced both suppression and stimulation of the immune system.[13] Studies of behavioral reactions in cattle and sheep exposed to sonic booms and low-altitude sonic flights recorded no adverse effects.[14] Changes in progesterone and estrogen levels and an increased incidence of premature births and abortions were recorded in one study of the effects of aircraft noise on pregnant cows.[15]

Chemical composition

Crude oil, natural gas, and emissions from processing facilities are all complex mixtures of a large number of hydrocarbons and, potentially, metals for which the composition varies between geological formations.[7] The difficulty in measuring the exposure to a particular chemical and the problems in predicting the potential for interactions of these compounds complicates investigation of any toxicological effects. "Weathering" may remove the more volatile and water soluble components. This variation in crude oil composition may explain some of the variations seen clinically since acute clinical signs seem to be related to the more volatile fractions.[4] The hydrocarbons in crude oil and natural gas are primarily aliphatic and cyclic structures. The most frequently reported metals in crude petroleum are vanadium, chromium, nickel, and iron.[7]

Sour gas is natural gas containing sulfur compounds. The chemical composition of sour gas varies between geological deposits. Gaseous and volatile sulfur compounds include hydrogen sulfide, carbonyl sulfide, carbon disulfide, methyl-, ethyl-, and propyl-mercaptens. Hydrogen sulfide is usually the most significant sulfur-containing constituent and the content of hydrogen sulfide varies between wells. Other acid forming emissions of interest associated with petrochemical production include nitrogen oxides, ozone, and sulfur dioxide. Elemental sulfur is also produced. Information regarding the toxicology of these compounds in cattle is limited. Some work has been done on hydrogen sulfide and elemental sulfur. Experimental work from laboratory studies and human observation has been reviewed.[16,17]

Clinical and Pathological Features of Petroleum Ingestion

Clinical signs for a group of cattle that has ingested petroleum hydrocarbons can vary from sudden death to no observable effects. The clinical signs of petroleum poisoning in cattle have been summarized from published case reports.[7] In some cases, the only adverse effects produced after ingestion of large quantities of petroleum products are anorexia, decreased rumen motility, mild depression, unthriftiness, and weight loss for a period of several weeks.[4] Crude oil has been found to destroy rumen flora and the enzymatic actions of rumen fluids. Crude oil may also inhibit the absorption of fat soluble vitamins.[3] Hepatopathy and renal tubular nephrosis have also been reported in some cases of exposure to petroleum products.[4] Ketonemia, ketonuria, albuminuria, leukopenia, eosinophilia, hypomagnesemia, and elevated serum glucose have been documented.[7]

Petroleum hydrocarbon poisoning in ruminants typically involves the respiratory, digestive, and central nervous systems.[4] Acute bloat may also cause death. The bloat is attributed to expansion of highly volatile hydrocarbons. The acute toxicity of the petroleum mixture is determined by its aspiration hazard and its irritant effect on pulmonary tissue.[4] Highly volatile and low viscosity hydrocarbons increase the risk of aspiration and irritation to mucous membranes because of the defatting and denaturing capabilities of the solvent components. Aspiration of petroleum products can result in the formation of pulmonary abscesses, with death occurring after several weeks of progressive decline in appetite and physical condition.

The lung is a commonly reported target organ particularly for unweathered highly volatile crude oil.[4] Following oral ingestion in cattle, the lungs may have contact with petroleum by three mechanisms: direct exposure when petroleum is aspirated during emesis, direct exposure when volatile hydrocarbons are eructated and inhaled, or hematogenous exposure where the hydrocarbons are absorbed and carried by the blood to the lung tissue. Aspiration of ingesta during emesis is considered to be the most common cause of pneumonia resulting from petroleum ingestion.

The toxicological effects of primary inhalation exposure to most petrochemicals have not been investigated in cattle. The toxicity of hydrogen sulfide has recently been reviewed for laboratory animals and humans.[18] Sulfides inhibit oxidative enzymes in a manner similar to that of cyanide, particularly enzymes involved with oxidative phosphorylation. Hydrogen sulfide is an *in vitro* inhibitor of cytochrome oxidase. Tissues most susceptible to hydrogen sulfide toxicity are those with exposed mucous membranes and those with a high oxygen demand: nervous system, respiratory system, reproduction and development.

Sulfide also causes both potassium channel-mediated hyperpolarization of neurons and potentiation of other inhibitory mechanisms. It is not clear whether these processes are similar to those in anoxia. Changes is perinatal and adult brain neurotransmitter content and release may be related to clinical impairment of cognition. Hydrogen sulfide exposures at concentrations below the current occupational limits cause physiological changes in pulmonary function. Laboratory studies of fetal and neonatal brain tissue have found evidence of abnormal development, and the long-term consequences have not been assessed.[18]

The potential for contamination by crude petroleum is determined by analyzing for BTEX's (benzene, toluene, ethylbenzene, and xylene).[7] The toxicology of these compounds have not, however, been examined for cattle. Acute benzene toxicity in humans may kill by depressing the CNS or by producing fatal cardiac arrhytmias. The major chronic effect of benzene in humans is hematopoeitic toxicity. The acute toxicity of other alkylbenzenes, including toluene, xylene, and ethylbenzene, in humans is CNS depression.[19]

Case reports of petroleum ingestion

Early North American reports of petroleum ingestion by cattle describe few details of the clinical and pathological syndromes observed.[3,5,20] Vague gastrointestinal and/or neurological signs are described with outcomes varying from complete recovery to lack of return to normal condition or production. Descriptions of the dose and composition of the product consumed are also vague.[3] An account of three cases of poisoning with tractor paraffin in grazing cows was recorded.[21] One of the most widely quoted papers in the literature was written by McConnell in 1957.[22] He summarizes his observations from 41 years of practice in Oklahoma. Problems due to hydrocarbon ingestion, salt toxicosis, and heavy metal poisoning are detailed. Sudden death resulting from bloat was attributed to sudden expansion of volatile compounds. Toxicity was attributed to the percent of volatile constituents and sulfur compounds.

The effects of oil field pollutants on vegetation and farm animals were reviewed by Monlux *et al.* in 1971.[23] The report emphasizes toxicity related to ingestion of salt water and lead. A "poor nutrition-lack of water" or "salt injury complex" is described. Poor doing and unthrifty animals are attributed to chronic salt poisoning and resulting poor nutrition and inadequate intake of water. The suggestion was made that volatile constituents are responsible for signs of toxicity other than bloat. The toxicity of waste petroleum products was reviewed by Gardner.[6] The use of used crankcase motor oil as a cure-all for lice, ringworm, and other conditions were discussed. The three cases described occurred after used petroleum products were left around the farm yard accessible to calves.

During 1978, the Oklahoma Animal Disease Diagnostic Laboratory investigated 29 cases of oil field related poisonings which involved petroleum hydrocarbons.[24] Five case reports from this group are presented. Cases involved leakages from tank batteries and access to unfenced slush pits. Morbidity and mortality rates varied between herds.

A case of crude oil poisoning in a herd of dairy cattle near Calgary, Alberta was described.[25] Fifteen of the farmer's 125 dairy cows died within two to three weeks of calving in 1971. The cows were described as having "milk-fever signs" by the farmer. In a subsequent lawsuit arising from the incident, the Supreme Court of Alberta upheld the veterinarian's diagnosis of crude oil poisoning. The judge stated that "the plantiff (the veterinarian's client) does not have to prove beyond a reasonable doubt; he has to prove on the balance of probabilities."

An episode of kerosene poisoning was reported in a group of 51 dairy heifers drinking from a contaminated stream.[26] Ten of 51 animals died or were destroyed within the first three weeks. Post-mortem findings from the dead animals included fatty change in the liver and focal hepatitis, aspiration pneumonia, and interstitial nephritis. Several of the surviving animals had evidence of acute liver damage based on analysis of serum enzymes. Chronic poor performance of the surviving animals led to eventual slaughter of the remaining animals. No persistent pathology was detected in the surviving animals.

It is common practice for cattlemen to use diesel fuel as a carrier for fly spray.[27] Dermatitis in 90% of cows in a 50 cow dairy were associated with the use of Diesel No. 1-D as a carrier for fly spray. Petroleum distillates applied to the skin cause irritation, thickening, and fissuring. Gasoline, kerosene, and diesel fuel oils cause defatting, drying, and severe inflammation of the skin.[4]

Thirty of 200 ewes died or were euthanized during a 21 day period following a 1 day accidental exposure to natural gas condensate.[28] The principal cause of the mortality was aspiration pneumonia, but myocardial degeneration and necrosis, renal tubular damage, gastritis, enteritis, and meningeal edema and hyperemia were also observed. The source of the condensate was a previous valve leak on the storage tank that had contaminated the surrounding soil. Heavy rains saturated the soil and the condensate came to the surface and accumulated in pools of rain water.

Experimental exposure to crude oil ingestion

Dosing cattle with sweet crude, sour crude oil, or kerosene induced anorexia, weight loss, mild mental depression, and usually decreased plasma glucose content.[29] Vomiting and moderate to extreme bloating occurred most often with the volatile sweet crude oil and not at all with the kerosene. Pneumonia developed sooner, and was more intense, and death usually occurred earlier in calves given sweet crude oil or kerosine.

Groups of four animals were stomach tubed with single oral doses of Pembina Cardium crude oil at 20, 40, 60, and 80 ml/kg.[3] Mild transient bloat and discomfort were seen at 20 ml/kg PCCO. Higher doses produced variable responses within groups. Two animals were similarly affected to the 20 ml/kg group while two animals vomited large amounts and aspirated it into the lungs. Mild neurological signs were observed with the act of vomition. Lipid droplets resulted in mild vacuolation of hepatocytes. Mild to severe thymic cortical atrophy was seen in all animals.

Case reports of exposure to sour gas emissions

Interest in the effect sour gas emissions might have on livestock was based in part in questions arising from two previous investigations of sour gas exposure in the province of Alberta.[30-35] The first of these investigations followed a sour gas well blowout at Lodgepole, Alberta in 1982. On October 17, 1982 an Amoco Dome Brazeau River well located 20 km west of Lodgepole, Alberta blew out of control for 67 days. Recordings of hydrogen sulfide varied up to 30 ppm on one occasion and beyond 30 ppm on four occasions.[33]

Some statistically significant biochemical changes were noted in a study of 50 exposed cattle, but the changes were transient and reversible.[36] Caution was advised by the investigators in interpreting these observations when assessing suspected clinical disease in the animals.[35] No epidemiological studies were performed.[35] Laboratory submissions from the review area were monitored. No changes or trends could be ascribed to the well blowout, but analysis was limited as the laboratory submissions did not represent a random statistically valid sample of the occurrence of abortions and congenital defects.[37] After examining the above information, the review board concluded there was insufficient evidence to draw conclusions concerning the effects of the blowout at Lodgepole on livestock health.[35]

There appeared to be more problems identified by producers during 1983 and the period immediately following the blowout than had been recorded before the blowout or at the time of a retrospective survey in 1985. However, there were no records of other variables that could have changed during the study period.[33] The researchers reported that there was no concrete evidence to support many of the problems described or any baseline studies from which to work. The problems identified were not consistent through the producer group.

The second investigation of livestock health after a sour gas release followed the September 24, 1984 blowout of the Drummond 6-30 sour gas well near Claresholm, Alberta. The well was brought under control September 28, 1984 approximately 88 hours later. It was unlikely that livestock was exposed to concentrations of hydrogen sulfide over 5 ppm. Detailed investigations were carried out on four farms. Only a preliminary investigation was conducted on a further 12 farms. Owners of four of the sixteen farms felt that emissions from the Drummond well had caused significant disease in their livestock, while the owners of the other farms reported transient irritation or no effect. The investigating team concluded that exposure to sour gas may have been a significant factor for one farm within 2 km of the well site. The role of sour gas as a cause of disease on the other three farms seemed unlikely, but was not completely ruled out.[34]

A pipeline, carrying natural gas (> 30% H_2S) and condensate, was discovered leaking into a river valley in an intensive ranching area prior to the start of calving season. There was no association between calf loss and herd distance from the leak, wind exposure or location in the river valley (p>0.33). There was no significant association between reported irritation signs or odor reports at the time of the pipeline leak and subsequent calf loss (p>0.32). Management changes reported to be in response to the pipeline leak were identified as risk factors for total calf loss rate in project herds (p<0.04). Other herd level risk factors associated with increased calf loss rate included a median calving date in February (p<0.05) and the percentage of twin births (ρ = 0.4141, p< 0.05).[38]

Experimental exposure to hydrogen sulfide

Laboratory studies of the effects of hydrogen sulfide exposure on cattle have been summarized.[17] At 20 ppm for 21 days, Hayes reported slight lacrimation and no change in milk production in mature dairy cows.[39] Calves exposed to 20 ppm hydrogen sulfide and various concentrations of ammonia for 7 days exhibited distress, lethargy, restlessness, coughing, irregular respirations and dyspnea, photophobia, keratitis, corneal opacity, nasal irritation and epistaxis.[40] The odor threshold in humans for hydrogen sulfide is 0.01 to 0.03 ppm. The 8-hour occupational exposure limit for H_2S in Alberta is 10 ppm. Keratoconjunctivitis and lung irritation may occur in humans at 20-50 ppm H_2S. At 500 ppm unconsciousness and death occur within 4-8 hours and at 1000 ppm breathing may stop in 1-2 breaths.[41]

Exposures to other oil field chemicals

The production of some crude oil wells may be more than 95% salt water.[42] The concentration of NaCl ranges from 5,000 ppm to 200,000 ppm with an average of 40,000 ppm. Sea water contains about 20,000 ppm and concentrations greater than 10,000 ppm can cause sodium ion toxicity. A heifer with access to an open slush pit was observed to be dehydrated, uncoordinated, and to have abdominal pain. Post-mortem examination findings included hemorrhagic enteritis, hydroperitoneum, and GI contents with 50,000 ppm Na. In a second case, water collected near an oil well where some heifers were seen drinking prior to their death contained 12% total salts. Post-mortem examination of the heifers revealed rumenitis and pulmonary edema.

Neurotoxicity resulting from ingestion of triaryl phosphate in cattle has been reviewed.[43] Clinical signs of cholinesterase inhibition may or may not be detected. Delayed neurotoxicity cannot be predicted by inhibition of blood ChE's. Signs of delayed neurotoxicity can be observed between 2 to 25 days following suspected exposure. Neurologic deficiencies of the antigravity muscles and the muscles of the urinary bladder and larnyx manifested by urine dribbling and muteness in adult cows have been reported in exposed cattle. Pathological findings include axonopathy and myelin degeneration.

Accidental release of diethylene glycol by the petroleum industry has resulted in exposure to cattle, although other sources of exposure are also common. Pathologic changes in the liver and kidney of experimentally exposed cattle were recorded. Changes noted in the trigeminal ganglion were proposed as a useful biological marker of DEG intoxication in cattle.[44]

Methanol has been used as an antifreeze in production and transportation equipment as well as to prevent hydrate formation in gas wells and pipelines. Oil field related exposures have been reported for cattle. Clinical signs include disturbances of locomotor activity, decreased respiration, frequent chewing motions, impaired vision, and decreased sensitivity to painful stimuli.[7,45]

Diagnosis

Be "claim conscious" in your investigation if there is suspected injury or death from oil field wastes. The possibility of litigation necessitates careful observation and detailed, accurate record keeping. The use of a specific post-mortem examination and clinical examination protocol has been suggested. Chemical analysis of gastric contents, urine, blood, and body tissues can be used to verify and estimate the amount and type of material ingested through examination for the suspected compound and its known metabolites.[3]

Samples of the suspected materials should be submitted along with tissue samples. The laboratory should be contacted in advance to make sure it can run the appropriate analysis and to obtain instructions on preferred sampling protocol. Do not use plastic containers for the collection of samples suspected to contain petrochemicals as the container may contaminate the sample. The lab will often ship out collection containers. Glass jars secured with lids lined by aluminum foil are suggested for samples containing hydrocarbons. Strict sampling labeling and handling protocol is necessary to ensure no samples are mixed up or that sample quality is not compromised. A record of the chain of possession may be necessary. Lists of suggested samples for submission in cases of suspected petroleum related product ingestion have been published.[4,46] Collect samples of all major organ systems and potential sources of exposure.

Losses following acute exposures in cattle are not usually difficult to diagnose when signs and diagnostic work-up occur shortly after ingestion of the petroleum product. Oil can be recovered from the gastrointestinal tract or lungs. Tissues can be examined under a black light because many petroleum compounds fluoresce yellow or yellow-green under long wavelength ultraviolet light. Hydrocarbons, particularly alkanes and alkenes, can be detected by gas-liquid chromatography (GC) or infared spectrophotometry on extracts of ingesta, tissues, and feces. The chromatogram generated from the tissue samples can be compared to the chromatogram to one from the suspected petroleum source.[3,4] The use of "fingerprinting" to establish the source of ingested petroleum has been reported.[24,28] This technique is successful because each crude oil and petroleum product is composed of a distinct set of compounds at differing concentrations.

The length of time chromatography can detect and identify an petroleum product is unknown relative to the point where the product is no longer visually detectable in the carcass. This may be up to two weeks following ingestion. This technique should increase the sensitivity for detection of petrochemical ingestion after this period.[3] The tissue distribution and bioaccumulation of specific components of complex petroleum mixtures is not well established. This information is necessary to the development of diagnostic methods to identify residual petroleum constituents and aid in retrospective investigations. These methods could be used in the risk analyses for assessing the suitability of livestock exposed to petroleum products for slaughter and human consumption.[3] Exposed animals must be withheld from market until there is no evidence of tissue residues that could suggest a potential public health threat.[4] Currently, information on appropriate "withdrawl times" for many of these chemicals is not available.

Specific biochemical markers which persist after petroleum ingestion are other potential sources of diagnostic methods for past petroleum exposure. Hepatic microsomal enzymes (MFO) are the best studied biochemical indices. Polycyclic aromatic hydrocarbons induce these enzymes in many species. Enzyme induction is not, however, specific for petroleum exposure because these enzymes are induced by many different toxins. Use of enzyme induction as a biochemical marker of petroleum ingestion is also limited by lack of information on variables affecting the rate of decline for the induced activity. Extrapolation between species is difficult because of interspecies variation in activity. Enzyme induction provides only circumstantial evidence for exposure to a toxin at an undetermined time in the past.[3]

Problems in diagnosis arise when the effects of ingestion or inhalation are delayed or where non-specific chronic ill-health effect is attributed to past exposure to petroleum products. Delayed effects are reported in humans after long term inhalation of specific hydrocarbons such as n-hexane and benzene.[3] Difficulty in evaluating an association between exposure and problems occurs in animals which are not seen acutely affected or appear to have recovered from acute symptoms. Several months after the alleged exposure the owner could potentially suggest that, as a direct result of the exposure, the cattle are chronically affected by vaguely-defined ill-health, poor weight gains, reproductive dysfunction, or increased susceptibility to rare conditions. This type of case can be extremely frustrating to resolve through a retrospective investigation. For example, diagnostic post-mortem examinations are of less value once gross evidence of the oil has disappeared from the carcass.[3]

The resolution of these challenging investigations depends on eliminating all other possible explanations, circumstantial evidence on the likelihood of exposure, and the probability that petroleum is associated with the disease outbreak or production shortfall.[25] The unique contribution of the practicing veterinarian in the investigation of these cases is the ability to examine the herd. Productivity is assessed to determine if there is a shortfall. The occurrence and importance of other known risk factors for the loss can be measured and their role evaluated. An estimation of loss associated with exposure to the environmental toxins, if any, can be calculated to determine appropriate compensation.

Examination of the herd

The initial objective of the herd examination is no different from any other herd disease investigation. Define the problem. The existence of an outbreak or productivity problem must be established. Given that there is a problem, a specific case definition must be developed. Next determine what factors within the environment are related to the occurrence of the problem. Which cattle or groups are affected, where are they located, and when did the problem begin? Formulate a diagnosis and develop a plan to verify the diagnosis and resolve or reduce the problem identified. A good general reference of herd examination has been published and some of the following material is based on suggestions by the authors.[47] Time is very important in this type of investigation. Delay in observing the herd and collecting information can result in critical losses of information. Removing or minimizing exposure to the cattle can reduce potential impact to the herd.

Initial contact

Obtain client information and presenting complaint including the legal land description. Have the client gather necessary records prior to the visit. Some suggest having the client fill out a preliminary questionnaire prior to the visit to save time and allow better planning of the field examination. Arrange for the cattle to be available for examination. If possible, it is useful to examine the herd in its regular location before having the group confined for a detailed examination. Suggesting the client feed at the time of the visit or just prior to the visit can facilitate the examination. If possible, all people working with the cattle should be available during the visit for questioning. A crude case definition may be constructed from the initial information provided. The case definition will determine the focus of the field examination.

Equipment suggested for the herd visit includes: notebook and pens, calculator/lap top computer and portable printer, camera/pocket tape recorder/video camera, sample collection equipment and containers, measuring tape, weigh tape, calf scale, ear tags and applicator, livestock markers, portable photocopier, current county map, and an animal health technician to assist with documentation and sample collection.

History

On approach to the farm, take advantage of any opportunity to observe the undisturbed herd for attitude and activity pattern. A complete and accurate history may be the most important part of the investigation. Some basic information must be collected prior to "jumping into the problem" or it may get missed or forgotten later. All information should be recorded by investigator in ink. Verify client data: name, address, phone, fax; ownership of cattle; off farm jobs; identity of all individuals working with the herd; and legal land description. Collect herd data including the type of operation(s) feedlot, cow/calf, dairy, or a mixed operation (other livestock or crops). Obtain a complete herd inventory including: classes (age/production groups) of cattle within the herd and number in each group, herd breed composition, and whether the herd is purebred, commercial, or mixed. How many years has the owner been in operation and have there been any recent changes in herd size or herd management?

Examine the available herd records. What types and quality of records are available for current and previous years including DHIS (supervised or owner sampled), calving records, treatment records, breeding records, pregnancy test records? Are there individual level or herd level records and are individual animals uniquely and permanently identified? Sources of information may include: individual cow cards, calving books, calendars, auction mart receipts, veterinary/drug bills, feed bills, DHIS mail copy or data transfer options, labels off supplements and pharmaceuticals. Obtain copies for detailed analysis in office and have the client explain the record system and abbreviations used. Don't forget historical information and records for the period preceding the outbreak.

Define the problem and clarify the principal complaint. What specific abnormalities in health, behavior, and/or production has the client noted in the herd? How many and which animals/or group of animals are affected? Is there a specific age group, pen group, pasture group, production type, sire group, birth cohort exhibiting the problem. Have the client describe one or several individual cases. How long did the signs persist?

Orient the problem in space and time. Sequence of events is important. When was the problem first recognized? When was the potential exposure first recognized? How were the following cases distributed in time: point source, propogative, sporadic or endemic. Sketch out an epidemic curve. Where are (were) the affected animals located (create a point map)?

Examine any available information regarding the previous disease history of the herd. Obtain informanostic work (pathology reports) and/or treatment or control attempts. Retrieve specific information on products used, dose, and duration of therapy. Examine herd culling rate and reasons for culling. Record the source of replacements for the herd and the date and identity of recent additions. Has there been any transient introductions to the herd? Inquire about health problems in adjacent herds and access to wildlife. Is there any concurrent human disease.

Construct a herd management profile (general) for the time of the visit. Establish the location of the herd (and specific management/contemporary groups within the herd)-barn (type), drylot, pasture. Record the type of feed, amount fed, frequency, source (local grown, commercial), use of supplements (farm mixed, commercial), any available analysis (commercial "off the bag" label or faxed from company), and the source of water (analysis). Record vaccination and routine herd treatments. Brand name is best (less confusion) and if any question, ask to see receipts. Specifically determine which groups within the herd were vaccinated and dates vaccinated, if available. Inquire about parasite control, vitamin/trace mineral injections including the dates, dose, and groups treated.

Ask about the immediate herd environmental conditions including shelter availability, and the type and amount of bedding provided. Obtain data from local weather stations e.g. Environment Canada. Ask about the type and specifications of ventilation if indoor housing used. Finally record breeding management information. Does the herd owner use AI, pasture breeding, or both? Record the dates bulls put in/removed. Discuss the strategy for genetic improvement in the herd (crossbreeding or linebreeding or inbreeding). Develop a specific management profile of more specific questions as dictated by the problem that for example would include milking management, calving management (beef, dairy), breeding management (beef, dairy, natural or AI), management of initial processing (feedlot).

Structured questionnaire may help to remove examiner bias from the interview, but may also limit the flow of conversation and information transfer with the client. Specific questions about management or environment may be related to a path model for a specific problem. The focus of questioning is on identification of the key determinants of disease or the factors in the causal pathway that have been identified as risk factors in scientific studies and that are subject to manipulation.

Examine the herd

Ideally the examiner should have the opportunity to examine the herd in its natural environment. Some level of skill and cooperation from the herd owner is necessary to be able to observe the herd without disturbing them initially so behavior, attitude, appetite, and their location within the facility can be recorded. A complete "walk through" of the herd and facilities provides an opportunity to ***verify the information obtained in the history*** through additional inquiries and direct observation. Photographs, videotape, maps, and sketches are valuable tools. Observations of individual animals should include eartag, sex, color description, breed, and age class if possible.

Establish some measure of the stocking density. How many animals are there and in how much area? Determine pen size. The owner may know pen size, pace it out, or measure from aerial photos. Estimate how much of the area is functional space (trees, standing water, old machinery). Subjective estimate of degree of crowding are also useful. Published values on suggested area per animal unit for different management systems are available.

Evaluate nutritional management

Evaluate all potential feed and water supplies and record the types of plants (cultivated or natural pasture). Drive, ride, or walk the available pasture and record the amount and quality of forage available if grazing. Evaluate the potential for ingestion of soil if grazing on a suspected contaminated site. Watch for poisonous plants and talk to the local experts in this area about what problem plants are common. Record whether or not ground fed, if not grazing. Are the feeding areas stationary or rotated? Is the feeding space adequate? This can be physically measured and compared to published values. Observe animals eating and note whether animals "line up" to get at the feed and degree of fighting. Evaluate the amount of wastage and the visual appearance of feed. Verify the reported composition and assess visual quality/freshness/palatability. For home made rations, examine fibre length and evenness of the mix.

Evaluate the feed bunk management for the presence of old feed and availability of feed. Verify intake through weigh in and weigh back if possible or weigh representative sections of feedbunk and extrapolate. Examine the feed storage area and record the amount and visual quality of remaining silage or hay. Is the storage area covered or open to elements and does the amount available correspond to reports of the amount being fed.

Examine the source and consider the adequacy of the water supply. Is the principal water source a dugout, run off, spring, well, or water hauled to a tank. Record any problems with fecal contamination, algae, high mineral content. Evaluate the accessibility of the water source for all ages in the pen and the number of livestock waters per number of cattle in the pen.

Record where any supplements are located, how fed, protection from elements, freshness, and evidence of recent intake. Verify amount fed (weigh container used to measure). Finally collect samples of all feed and water sources for analysis. Use a defined and consistent protocol for sampling.

Examine the environment

A complete examination of the outdoor environment will include observations of topographical features. Is the field in a valley, on a hill side, or a flat plain? What is the available protection from environmental extremes: man-made shelters, wind breaks, wooded areas. What are the apparent drainage characteristics of the pen or field. Evaluate the importance of the presence of mud, standing water, of a dust problem, and availability of dry areas for rest and feeding. Record and photograph the amount and type of bedding provided. Record any potential access to old machinery, garbage dumps, industrial sites. Note waste/carcass disposal sites and the degree of fly/predator problems.

Evaluate the indoor environment

Examine the indoor environment for sanitation and hygiene. Examine the flooring (type and condition) and evaluate the cleaning and waste disposal protocol. Assess ventilation and heating system and, as appropriate, maximum and minimum temperature, air changes per hour, humidity and condensation, position and size of inlets and fans, and presence of drafts. Measure stall design and dimensions and stall bedding type and cleanliness. Evaluate the floor plan and movement of attendants and animals within the unit and the adequacy of lighting.

Document all potential sources of exposure

Visit, photograph, and sample potential sources of petrochemical exposure. If possible, cooperative investigations with the petrochemical company and the appropriate government environmental regulatory agency are much more likely to produce results than a strictly adversarial approach. Guidelines for sample collection should be obtained from the laboratory toxicologist prior to the visit. If possible, have a third witness for sample collection and photograph collection and packaging of samples.

If not already done, minimize potential impact by removing cattle from the suspect pasture, fencing the problem area, providing alternative sources of food and water, washing if dermal exposure has occurred, and providing supportive therapy such as fluids, laxatives, and broad spectrum antibiotics as appropriate.

Individual animal detailed examination

Individual animals may be restrained for detailed clinical examination. In most cases it is not possible or practical to examine the entire herd. The group examined should if possible contain individuals the herd owner feels are normal, some in the early stages of the condition and some in the later stages of the disease. A standardized examination protocol can improve the usefulness of the findings. Include an estimate of age in findings if this information is not available in herd records. Photograph any unusual observations. Photographing a sample of animals from the herd will also provide an additional record of general health and condition at the time of the visit.

A general visual inspection of many animals from the herd may be done in the pen or on pasture. A complete description of the animal inspected should be noted where possible with the following observations: behavior and general appearance, gait, voice, body condition score, appetite, conformation, defecation, fecal consistency, skin, urination, cud chewing, and posture. A visual inspection of body regions should include: head (eye or nasal irritation), neck, thorax, respiratory rate, respiratory rhythm, respiratory depth, type of respiration, thorax symmetry, respiratory noises or stridor, abdomen, external genitalia (evidence of abortion), mammary glands, and limbs.

Examine all available dead or moribund animals. Necropsy may be done in the field or arrange for transport of the carcass to a regional lab. Examine and sample all organ systems. A standard protocol may help avoid errors of omission. Extra samples frozen or kept in formalin can be discarded if not needed but cannot be retrieved later. Necessary space and costs of storage must be considered. Don't forget animals that have been sent to slaughter plants as a valuable source of information and samples for laboratory analysis.

Sampling and laboratory testing

The cost and accessibility of animals for sampling are the major limiting factors. Laboratory testing can be used to confirm diagnosis, define risk factors, and evaluate the effectiveness of treatment and control strategies. Avoid "fishing expeditions". In deciding what tests to do, the following questions can be considered. Are the specificity and sensitivity of the tests understood and can the laboratory define normal for a particular test? Call the lab to confirm sampling collection, storage, and shipping protocol if in doubt. Remember that the cost of additional samples is low in comparison to cost of resampling or lost opportunity. Consider establishing a serum bank for later analysis or confirmation of laboratory findings.

Depending on the question asked, samples may be random, systematically random, stratified random or a selection of "advanced cases", "early cases", and /or "normals" from the herd. The examiner must be able to correlate lab results to individual animals and clinical exam results; therefore, you may have to tag animals as samples are collected. The sample size depends on the question being asked, the size of the herd, the magnitude of type I and II errors an examiner will tolerate for a given test and the expected relevance of the problem in the population (practically this value is usually difficult to find in the veterinary literature). A sampling strategy can be designed to estimate the prevalence of an attribute in a herd or group, estimate the average of some parameter, or detect the presence of a specified attribute in a herd. Thirty animals will usually give a useful estimate of the mean for many tests.

Records Analysis

The quality and completeness of records will vary greatly between operations. Some degree of ingenuity and probing may turn up useful information in unexpected places such as: veterinary/drug bills, auction mart receipts, old calendars, pocket diaries, calving books, feed bills, financial records of number of animals bought and sold, bulk tank SCC and bacterial numbers. Consider spot checking records for accuracy.

Treatment records may be difficult to obtain in the face of an outbreak. If record compliance is poor, it may be useful to have the producer mark animals treated with color marker coded for the day treated. This can provide useful information on the treatment/relapse history of an individual animal and a better estimate of how many have been treated in total.

For more complicated problems in larger herds, it may be necessary to copy the herd records and have them entered onto a software program for detailed analysis. Some software requires limited or no data entry, for example, CowChip$ herd records option or PlotPlus from ADHIS. Know the analysis software you are using. There are many limitations to and errors in many available commercial software packages. For herds that do not have a current herd inventory list, chuteside collection of animal identification, color, breed, age, and BCS may be possible during routine processing.

Records can be analyzed and compared between exposure groups within the herd or information from other area herds, provincial averages, breed association or DHIS reports, published studies and production goals, or historical performance of the herd being examined. Accurate definitions of parameters analyzed must be recorded. Be careful when comparing parameters to findings from other investigators as there can be substantial differences in standardization of terminology and methods of calculation.

Detailed records may allow the calculation of group specific parameters of interest. The case definition is important. A quantitative assessment of disease or suboptimal production can be made and compared between groups within the herd or outside the herd. Distinguish between prevalence and incidence. Case-fatality rates, factor-specific attack rates, relative risk, and attributable risk can be calculated.[48] In comparing exposure groups within herds you must be able to account for differences in the occurrence of other known risk factors for the problem between the groups.

Statistical tests should be used where applicable to evaluate association between specific factors and disease. Note that statistical significance is not equal to biological significance. Remember the criteria for evaluating causality include the assessment of temporality, biological gradient, the strength of association, the coherence and consistency of evidence, the biological plausability or availability of experimental evidence, and to a lesser extent specificity of the association.[49] The epidemiological diagnosis is the pathological diagnosis and the list of key determinants or substantial risk factors identified in the herd investigation.

Reporting of Findings

The final step of the investigation is the written report. Verbal advice may be given throughout the investigation. Interim written reports may be necessary if the investigation is prolonged and provides credibility for final decision. Issuing interim reports minimizes concerns about credibility in situations involving potential litigation.

The style of the report must be appropriate for the intended audience. In many cases, you will be educating people that have had no previous contact with cattle. The report for the producer should contain a definition of the problem, summary of the findings, epidemiologic diagnosis, recommendations (short-term and long-term), and follow-up plans. A report intended for litigation and review by other veterinarians should contain a background and history of the problem, objectives of the investigation, methodology, results, hypothesis/causes, financial impact, recommendations, and appendices (lab reports, large tables and graphs, disease management checklists, etc.).

Follow-Up

Effective monitoring of the cattle to assess the effect of recommendations is critical to the success of solving herd health problems. Further history, examination, or laboratory testing may be required to verify the diagnosis. In many cases of suspected petrochemical toxicity, a settlement is reached based on the ability to eliminate all other potential risk factors because of limitations in exposure measurement and available toxicological data in cattle. **Attention to detail in the herd investigation is critical to achieving this end.** Laboratory analysis is an important part of any investigation. Many of the more complex oil and gas problems facing the veterinarian must be settled through the application of clinical and epidemiological skills rather than exclusive reliance on technology for a quick and easy answer.

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