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Radiation poisoning countermeasures that can be obtained minutes to hours following a nuclear accident, along with useful advice on potential urgent measures.

hoajda Raci,Julia loletto and lavio krotti

1. Hospital Pharmacy Unit, Padova University Hospital, Padua, Italy
2. Nuclear Medicine Unit, Department of Medicine (DIMED), Padova University Hospital, Padua, Italy
3. ARPAV Unità Organizzativa Agenti Fisici, Verona, Italy

***Corresponding author**

Julia loletto,
Nuclear Medicine Unit, Department of Medicine (DIMED),
Padova University Hospital, Padua, Italy.

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INTRODUCTION

Overview of nuclear crises and potential outcomes An accident of the nuclear kind is one that can reveal a very fluctuating number of individuals to radiation and isotopes [1]. The detonation of a military nuclear bomb is the worst-case scenario. The primary risk associated with radioactive fallout is exposure to outside radiation, which is a highly complicated situation.

Among the other potential causes of nuclear disasters are mishaps or acts of sabotage at nuclear power plants, such as the explosions in the reactors at Chernobyl (1986) and Fukushima (2011), which released significant amounts of radioactive materials into the atmosphere and had dire repercussions for the environment and the nearby population in particular [1, 3]. The most significant pathways of contamination were ingestion and external radiation from deposition on the ground, which were followed by inhalation and radiation from the "radioactive cloud" passing overhead. If I-131 was one of the radionuclides consumed Subsequently, the range of inhaled isotopes broadens, encompassing Ru-103, Te-132, I-131, Cs-134, Cs-136, Cs-137, Ba-140, Ru-106, and Ce-141 [4]. The potential exposure level of individuals is mostly determined by the urban conditions and environmental features of the affected area during the incident. For instance, national emergency management plans [5] might take the nuclear power plant's location into account to determine potential outcomes: plants up to 200 kilometers away from the nation's border (iodo-prophylaxis is possible, according to the plan [5, 6], people who reside more than 200 kilometers from the border (preventive measures, such as food restrictions and safeguarding livestock and agricultural products); and flora in non-European nations (no recommended preventive measures).

The detonation of radiological dispersion devices (RDDs) containing isotopes, sometimes referred to as "dirty bombs," can potentially result in nuclear emergencies [7]. Since fssion does not occur in this situation, the sorts of radioactive substances that can reach the environment or air and be inhaled are more restricted—likely just one. While the exact effects of a nuclear disaster like this are difficult to foresee, predictive analyses point to a relatively modest participant count and a low risk to public health from radioactive fallout [8].Despite the fact that many other isotopes can be utilized in RDDs, the possibilities can be logically reduced to the nine most accessible: cobalt-60 (60Co), cesium-137 (137Cs), californium-252 (252Cf), americium-241 (241Am), and cesium-137 (137Cs). strontium-90 (90Sr), polonium-210 (210Po), radium-226 (226Ra), iridium-192 (192Ir), and plutonium-238 (238Pu) [9].

An additional option to take into account is malicious nuclear pollution of the environment. The amount of time that passes between the radioactive material's dispersal and the population's contamination is crucial in this situation. One instance of this kind of situation occurred in the Goiania accident in Brazil during the 1980s, where two men took a source of cesium-137, which was sold in pieces, from an abandoned clinic. When the victims' signs of radiation exposure were not promptly identified, it resulted in their insufficient care and permitted the pollution to proliferate [10].

Last but not least, the polonium-210 poisoning of Alexander Litvinenko in November 2006 [11] raised concerns about the potential for direct contamination of food or drinking water.

While there are naturally significant differences between the scenarios mentioned above, certain isotopic pollutants are more prevalent than others. For this reason, it's critical to understand what antidotes are available and how much of them to take. We first provide a realistic, non-exhaustive list of the antidotes for the most frequent isotopic pollutants that are accessible (for the adult population) in this editorial. Next, we look at which antidotes have a safe profle—that is, those that can be obtained without a prescription in many countries.

are ready to be used in an emergency response to handle a major nuclear accident. It is important to emphasize that antidotes should only be used in extreme circumstances and only after consulting a doctor or other appropriate authority. This work focuses on the medical management of individuals involved in a nuclear emergency, and as such, it is primarily addressed to the medical personnel designated for treatment decisions.

Antidotes that are accessible for internal disinfection There are two kinds of contamination that can result from radioactive exposure: internal and external. Internal radiation exposure is the main health risk examined here. This can happen through ingestion, inhalation, or absorption through the skin, wounds, or burns.

The main objective of internal decontamination is to enhance radioactive excretion and inhibit absorption. Cleaning up after contamination is more effective the earlier treatment is started because the situation is almost irreversible once the isotopes have been absorbed by the tissues. Ionizing radiation-induced biological damage can result in either long-term carcinogenic effects or deterministic or stochastic effects, such as acute radiation sickness (ARS) [10].

The severity of acute radiation sickness is directly correlated with the radiation dose that was exposed to, and it manifests hours or days after exposure. Skin rashes, dermatitis, anemia, leukopenia, and, in the worst situations, mucosal hemorrhages are among the most typical symptoms. It has been calculated that the absorbed dose needs to reach in order for ARS to start minimum of 0.5–1.0 Gy [12]. Long-term effects are probably more common.

The higher the radiation dose absorbed, most likely, but it's hard to pinpoint a cutoff point beyond which they may be ruled out. These long-term effects are also not dose-dependent in terms of their intensity, and they are characterised as stochastic due to their unpredictable nature and multivariate influence [13]. Because radiation alters the structure of nucleic acids, the most frequent results of a stochastic effect of internal contamination include leukemia, genetic abnormalities, and other types of cancer [14]. It is crucial to avoid radioactive incorporation and deposition in target organs as much as possible in order to reduce such stochastic effects. The majority of the chemicals employed in this process work by means of the following mechanisms: using sequestering agents to reduce gastric intestinal absorption, administering the non-radioactive counterpart of the radionuclide to displace it, building complexes with chelating agents, and consuming things that promote the excretion of radioactive elements [10]. The majority of the antidotes used in decorporation therapy are given off-label. The majority of these medications are not approved by regulatory bodies for this particular therapeutic indication. The only antidotes approved for decontamination purposes are potassium iodide (KI), calcium-diethylenetriaminepentaacetic acid (Ca-DTPA), and zinc-diethylenetriaminepentaacetic acid (Zn-DTPA). KI is used for iodine, Prussian blue is used for radioactive cesium, and Ca- or Zn-DTPA is used for plutonium, americium, or curium.

Because clinical studies would not be ethically feasible, the majority of the safety and efficacy information that is now accessible comes from firsthand knowledge obtained in the aftermath of nuclear accidents and from research on animals [15]. After taking into account the most prevalent sources of contamination, international guidelines, and scientific literature, we identified a list of antidotes that may be suitable for broad usage in adult populations. Table 1 includes a list of these countermeasures, their recommended dosages, and how they should be administered. Beyond the scope of this research, the "cocktail" use of antidotes in individuals concurrently poisoned with various isotopes [16] is a complicated matter. However, the reader should be warned that one antidote may negate the effects of another (for instance, bicarbonate for uranium+DTPA for plutonium) may perhaps have negative side effects when combined.

Precautionary and expedient measures It is crucial to identify the radionuclide in question in order to determine the potential radiation dose that may have been absorbed and the best antidote, but this process can be time-consuming, particularly when dealing with alpha emitters [17]. Unfortunately, the most effective decontamination is dependent on timing, and postponing treatment might have negative effects on those who are polluted. There is no agreement on when to begin treatment with other medications, with the exception of stable iodine, for which WHO/IAEA recommendations on scheduling [6, 10] are provided.

hold off until internal dosimetry [17]. An antidote's effectiveness increases with prompt administration, but there should always be a positive risk-benefit ratio when using it.

When planning preventive campaigns for the general public, which may or may not have been impacted by the nuclear accident, additional critical factors to take into account are the antidote's accessibility, safety, and convenience of administration. Actually, there are now two categories into which the different approaches commonly used to handle a nuclear disaster might be placed: the precautionary approach and the urgent approach. Treatment is provided in respect to the committed effective dose and the implicated isotope under the precautionary approach.

Not yet widely accessible, these should be saved for those who are suspected of being contaminated or who were directly involved in the incident, as they are more likely to have been exposed to significant radiation doses. Briefly put, in large-scale nuclear accidents, the precautionary approach may be safer [21] and less expensive (at least in terms of antidotes) but carries the additional risk of a loss in effectiveness (due to a delayed administration). The urgent approach is likely to yield better medical outcomes (due to a speedier antidote administration).

If specific radioisotopes are found in the environment, it is usually advisable to give the few, affordable, and safe antidotes in an emergency situation (without using any individual dosimetry) to the population that is nearest to the incident, at the very least (mostly susceptible to pollution). This would guarantee a partial decontamination while allowing for the quicker and more effective management of a greater number of individuals. The precise region to cover would rely on environmental factors and the particular event. This method does not exclude conducting a proper individual dosimetric evaluation and switching to a more suitable antidote if needed.

Of the antidotes covered in the literature, adsorptive agents—like sodium alginate and aluminum hydroxide, which are frequently sold as over-the-counter products—potassium phosphate, which can be purchased as a dietary supplement, and potassium iodide (KI), due to its time-dependent mode of action, are potentially suitable for immediate, widespread use in the general population in the immediate aftermath of the nuclear accident. In the paragraphs that follow, We go over the research that has been done on these drugs. The pharmacological (and safety) profiles of every other antidote, many of which need to be given intravenously, are far more intricate.

As a result, they are far less appropriate for usage in an emergency situation. Beyond the scope of this paper, a thorough analysis of the literature on these latter kinds of antidotes is necessary.

There are antidotes that can be used extensively in accordance with a pressing strategy.

1) Adsorptive agents: aluminum hydroxide and alginates For the treatment of gastroesophageal reflux disease, alginates—typically in the form of sodium or calcium salts—are frequently utilized.

They come in a range of pharmacological forms, including oral solutions, chewable pills, and granules. Following consumption, They combine to create a very viscous gel that has the ability to bind alkaline earth elements like radium, calcium, barium, and strontium. As a result, it is highly advised that they avoid absorbing radionuclides. For seven days, the recommended dosage varies from 500 mg twice day (BID) to 1000 mg four times daily (QID). Following this time, a clinical assessment is advised [10]. Numerous investigations have been carried out in both preclinical and clinical contexts to verify the efficacy of alginates in inhibiting the uptake of strontium (Sr). Alginates can lower Sr absorption, according to human investigations carried out on volunteers [22–24]. A possible risk of a simultaneous decrease in the absorption of trace elements, including calcium (Ca^{2+}), was mentioned by certain writers [22–24].

On the other hand, alginates are not mentioned as having a side effect of increasing calcium excretion in guidelines for intervention during a nuclear accident. Alginates are consequently regarded as safe, having very few adverse effects in the majority of cases, and may be a suitable option for extensive, urgent operations.

The International Atomic Energy Agency (IAEA) states that individuals on low-salt diets or diabetics given alginate tablets containing a certain amount of sugar may infrequently have serious adverse effects [10]. However, these dangers might be promptly assessed prior to the antidote being administered.

When combined with the hydrochloric acid the stomach mucosa produces, aluminum hydroxide is used as an antacid. This lowers the acidity of the stomach's contents and relieves the symptoms of illnesses such as gastritis, gastric ulcers, and gastroesophageal reflux disease.Given that this agent can sequester the isotope, inhibiting absorption and increasing excretion, IAEA recommendations recommend using it off-label in situations of gastrointestinal (GI) contamination with a broad spectrum of radionuclides [10]. For this indication, 1-2 g of aluminum hydroxide per day is the recommended dosage. The IAEA recommends aluminum hydroxide for managing radioactive accidents for cobalt, polonium, and strontium, but only suggests using it for ammericium and plutonium. Even with the guidelines' recommendations, it is difficult to locate published research that supports the use of aluminum hydroxide in cases of radioactive contamination, particularly when the population is vast. According to a Bingham et al. study done on healthy participants.

[25], aluminum hydroxide can stop phosphorus from being absorbed through diet (though it's unknown at what amount). Although there isn't any evidence in the literature to support this theory, we can suppose that aluminum hydroxide can also impede the absorption of 32P because the pharmacokinetic features of the isotope are comparable to those of the native element. Aluminum hydroxide does not seem to cause any significant negative side effects, similar to alginates. It is frequently included in pharmaceutical formulations along with magnesium hydroxide, which balances the former's astringent effect with the latter's laxative effect. Despite providing scant scientific support, given the safety profile of these medications

and their possible beneficial effect in internal contamination, Both of these seem appropriate for use in a massive, immediate response to a nuclear incident.

2) In nuclear medicine, potassium phosphate PhoS 32 has been applied to oncology for both therapeutic and diagnostic purposes. On the other hand, accidental exposure to this radionuclide may necessitate decorporation. To prevent the absorption of radioactive phosphorus, guidelines suggest taking 250–500 mg of potassium phosphate orally four times a day, with meals and before bed. However, there are instances when consuming potassium phosphate is contraindicated, primarily due to hyperphosphatemia and moderate-to-severe renal impairment. Rare reports of minor gastrointestinal side effects during therapy, including nausea, lightheadedness in the abdomen, and (sporadically) diarrhea, have been made [7, 10, 26].

The general public can easily access potassium phosphate because it is available as a food supplement. Its safety profile is good. Nevertheless, no research has ever been published on the application of potassium phosphate for the treatment of internal contamination caused by radioactive phosphate, the length of time that such treatments last, or the quality of the data supporting their effectiveness.

3) Iodum in potassium

In contrast to the other medications that have been discussed thus far (potassium phosphate and adsorptive agents), potassium iodide is a well-known and specialized medication that is used as a "antidote" to prevent thyroid absorption of radioiodine. For the sake of completeness, we choose to include a brief paragraph on potassium iodide, however we still suggest the World Health Organization [6] and IAEA [10]. publications for a thorough exploration of the subject (which is outside the purview of this work). Following the incidents at Chernobyl and Fukushima, iodine and cesium were found to be the primary radionuclides causing contamination [27]. As a result, thyroid cancer became more common in the regions surrounding Chernobyl, which included Belarus, Ukraine, and the western portion of the Russian Federation. The primary source of radioisotopes of iodine is fission reactions using uranium. These isotopes can spread during a nuclear catastrophe and contaminate interior areas [28]. Iodine 131 and 125 are the two most important of the 14 radioisotopes derived from iodine; iodine 131 is also utilized in diagnostics. The thyroid stores 25–30% of the iodine 131 that the body absorbs.while the remainder is often swiftly eliminated along with the pee or feces [10]. Thyroid malfunction and thyroid cancer may result from the radionuclides that the thyroid absorbs. Because their tissues are more sensitive to infection, children and adolescents are especially vulnerable to this kind of harm [28].

The recommended medication to reduce radioiodine buildup in the thyroid is KI. Serum concentrations can be higher than those of the radioactive isotope when stable KI is consumed. This causes the thyroid to become saturated and accelerates the removal of the remaining circulating iodide, both radioactive and non-radioactive. The stable KI needs to be consumed as soon as possible following the suspected contamination in order for this mechanism to emerge and function as effectively as possible. (in less than four hours). When given after more than 24 hours, it even becomes dangerous since it could take longer for the radioiodine to be eliminated.

thing is already in the bag. The recommended dosage is based on the age-related variations in iodine (and its isotope) clearance. For adults and adolescents over the age of twelve, a single dose of 130 mg of KI is advised (however additional administration may be necessary after prolonged or recurrent exposure). In situations with low complement vasculitis, herpetiform dermatitis, Hashimoto's thyroiditis, Basedow's disease, and other autoimmune thyroid illnesses, it should not be used. KI has a modest (5× 10−7) risk of adverse effects when taken orally, but at a dose of 100–150 mg/die,It may cause older people to develop hyperthyroidism and babies to develop hypothyroidism. Hypersensitivity and, in the event of a protracted thyroid uptake blockade, a decreased metabolic rate are the most common side effects.

gland hypertrophy and activity [10]. Since they are most vulnerable, children, nursing mothers, and newborns should receive KI first [29]. The Polish government began a push to give KI to the general public after radioactive iodine was released into the environment as a result of the Chernobyl tragedy. Children that received KI one to four days after exposure had a committed dose to the thyroid that was almost 50% lower, according to a later evaluation of efficacy [30]. There is no data available from clinical trials, although there has been some information gathered from epidemiological investigations. The World Health Organization (WHO) carried out a systematic analysis to investigate the potential effects of thyroid blockage with stable iodine on the risk of thyroid cancer, hypothyroidism, Decisions regarding the most appropriate treatments should take into account not only clinical but also managerial and economic aspects.

Antidotes such as KI are already indicated for a priori urgent general administration. Judging from our analysis, other antidotes with an extremely favorable safety profle, such as aluminum hydroxide, could also be candidates for an urgent approach to large-scale nuclear events.

More systematic and evidence-based studies are needed, however, to support guidelines on the antidotes to administer, both to the general population and to the individuals most directly afected, in the event of a nuclear emergency

Additionally, the FDA advises using it first in youngsters and nursing mothers, and subsequently (and for larger exposures) in people between the ages of 18 and 40. People over 40 are less likely to experience the stochastic effects of iodine isotope exposure, hence the dosage of KI should be evaluated individually [29, 31]. You can smash the tablets and take them with milk, jam, or other fruit juice substitutes. Normally found in a hospital setting, this antidote may be given out to the general public in an emergency along with safety precautions.

CONCLUSION

Following a nuclear incident, a number of situations could occur, and it is difficult to predict which course of action would be appropriate in each case.

Intervention needs to be tailored to the specific radionuclides implicated, but sadly, this knowledge is unavailable prior to the catastrophe.

We have covered the suggested antidotes for the primary radionuclides connected to a nuclear emergency based on worldwide norms. Regulators have sadly not approved the majority of these treatments, and studies on their efficacy for decontamination have not been used to determine the recommended dosages. Since these medications are used in people for various causes, we can presume at least that their toxicity has been evaluated (Table 1). Apart from the selection of medication, the time elapsing between the contamination and the initiation of treatment is a crucial factor.

Dosimetric studies are required since the type of treatment needed is directly tied to the radionuclide's nature, but the most important thing is to begin treatment as soon as feasible. It is difficult to reconcile these two elements. Finding radionuclides that have accumulated in the environment and measuring the dosage that an individual has absorbed can take some time, but in order to prevent target organ contamination and deposition, therapies must be initiated right once. This poses the question of whether treatment need to be given immediately (the precautionary method) or only after contamination has been confirmed by individual dosimetric checks (the preventive approach) [21, 32–34].

We examined easily accessible countermeasures that may be provided in a highly safe manner using pharmaceutical principles. preventively, once an isotope has been found in the environment, to lessen the chance of integration in the general population (at least for those nearest to the occurrence). We concentrated on medication regimens that don't need hospital stays. These limitations limited the feld to potassium phosphate, aluminum hydroxide, and alginates. For the interest of thoroughness, we also took potassium iodide into consideration.

Aluminum hydroxides appear to be a good option for a safe, non-invasive intervention. Oral aluminum hydroxides are even advised by the IAEA guidelines to prevent the stomach from absorbing a number of radionuclides, including Am, Co, P, Pu, Po, and Sr [10]. Since their effectiveness for decorporation has not been specifically studied, this indication most likely results from their non-specific capacity to block gastrointestinal absorption. Accumulation of americium within Their ingestion results in the absorption of cobalt. Americium is absorbed in very small amounts, yet it remains in the body for a long time (mostly in the liver and bones). However, 10–30% of ingested cobalt crosses the gastrointestinal tract; roughly 5% is deposited in the liver and accumulates as vitamin B12 molecules, while its biological half-life is only predicted to be 6 days [9]. Similar to amerianium, plutonium passes slightly via the gastrointestinal tract and into the bloodstream. It is more frequently taken in by inhalation, where it is stored for a considerable amount of time in the liver and bones. Following intake, the percentage of polonium absorbed varies greatly; it then becomes irregularly distributed with Their ingestion results in the absorption of cobalt. Americium is absorbed in very small amounts, yet it remains in the body for a long time (mostly in the liver and bones). However, 10–30% of ingested cobalt crosses the gastrointestinal tract; roughly 5% is deposited in the liver and accumulates as vitamin B12 molecules, while its biological half-life is only predicted to be 6 days [9]. Similar to amerianium, plutonium passes slightly via the gastrointestinal tract and into the bloodstream. It is more frequently taken in by inhalation, where it is stored for a considerable amount of time in the liver and bones. Following intake, the percentage of polonium absorbed varies greatly; it then becomes irregularly distributed with 10% deposits in the bone marrow and roughly 45% in the kidneys, liver, and spleen [9].

Alginates are thought to prevent alkaline earth elements including strontium, calcium, barium, and radium from being absorbed through the digestive tract [10]. Research on volunteers aimed at blocking the uptake of strontium showed a significant decrease in its systemic absorption, which likely led to a reduced build-up in the bones [22–24]. Thirty to forty percent of the strontium that is consumed makes it into the bloodstream, where it is metabolized similarly to calcium. Thirty-one percent of the strontium that is in the blood is deposited in the bones, where it remains for up to a year. Similar in behavior, radium is mostly deposited in the teeth and bones.

While the majority of radium that is consumed (80%) is excreted in feces, the danger of radium contamination increases after inhalation [9]. There are other, even first-choice, countermeasures for all of these radioisotopes that would be better than antacids. However, the majority of these countermeasures call for intravenous administration and/or close medical supervision, meaning that the general public would not be able to access them; only those who have been most severely impacted by the nuclear event would be.

It is uncommon for phosphorus-32 to be listed among the radionuclides that are most likely to be discharged during a nuclear emergency [35]. If consumed, 60% is eliminated in a day, however The remainder most likely goes through the non-radioactive phosphorus metabolic route, with the bones serving as the primary target [35]. In cases of suspected contamination, some guidelines advise providing potassium phosphate due to the assumption of its biodistribution. This is because potassium phosphate would compete with the radioactive isotope and reduce its absorption.

Studies have not confirmed the effectiveness of potassium phosphate, and the general public is not at high risk of inadvertent phosphorus-32 exposure. Despite this, we have discussed this antidote because of its excellent safety profile with regard to toxicity. In the unlikely scenario of a suspected contamination, we think the benefits of the treatment would outweigh the dangers.Iodine radioisotopes that are inhaled or consumed have a relatively high permeability [9].

Once in the bloodstream, the thyroid is where they mostly gather. In younger patients especially, KI should be given as soon as feasible to prevent internal contamination because treatment delays reduce the drug's ability to saturate the thyroid gland [10]. Government agencies have already shown support for and intention to employ KI for the large-scale management of a nuclear emergency [17, 36].

Handling a nuclear crisis is an intricate procedure. A clinical reaction to the requirements of the population is always necessary, even though there are several variables to take into account and it is impossible to fully forecast how the event will affect things. The modes of action and safety profiles of antidotes for radioisotope decontamination differ. Clinical, administrative, and financial factors should all be considered while choosing the best course of action.

Antidotes like KI are already recommended for immediate broad administration. Based on our research, alternative remedies like aluminum hydroxide that have a very good safety profile might also be considered for a quick response to major nuclear accidents. To support recommendations on the antidotes to administer, both to the general public and to those most directly affected, in the case of a nuclear disaster, more thorough and evidence-based research is necessary.

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