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REVIEW

# Evolution of nuclear science and technology in Cuba from 1959 to the end of the 20th century

## Evolución de las ciencias y tecnologías nucleares en Cuba a partir de 1959 hasta finales del siglo XX

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## ABSTRACT

The assimilation and application of nuclear technologies in Cuba has allowed for sustainable development in sectors such as medicine, industry, agriculture and the environment, which has led to the creation of an adequate scientific-technical infrastructure and the strengthening of the socioeconomic pillars on which the nation is based. From the failed attempt to install nuclear weapons on the island, to the so-called Cuban Nuclear Program, which sought to solve the national electricity problem through electronuclear means; nuclear sciences have evolved and achieved great things, despite the country's limited resources. This historical process has not been properly studied and disseminated among the public not linked to the nuclear sector; therefore, it deserves to be analyzed from an objective, current and non-sensationalist point of view. Perhaps due to the ignorance of the population, which generally perceives the term "nuclear" associated with weapons or nuclear power plants, the applications and the work of professionals in this area of science in Cuba tend to go unnoticed. For this reason, the objective of the present work is to systematize the processes referring to the evolution of nuclear sciences and technologies in Cuba from 1959 onwards, taking into account the historical and political scenario that determines the efforts towards which nuclear applications are directed in each historical period, as well as their transcendental contribution to the sustainable development of the country, from the first years of the Revolution until the end of the 20th century.

**Keywords:** Nuclear Technologies; Nuclear Sciences; Cuban Nuclear Program; Sustainable and Sustainable Development.

## RESUMEN

La asimilación y aplicación de las tecnologías nucleares en Cuba ha permitido un desarrollo sostenible y sustentable en sectores como la medicina, la industria, la agricultura y el medio ambiente, lo que ha devenido en la creación de una infraestructura científico-técnica adecuada y el fortalecimiento de los pilares socioeconómicos sobre los que se sustenta la nación. Desde el fallido intento por instalar en la isla armamento nuclear, hasta el denominado Programa Nuclear Cubano, que buscaba la solución del problema electroenergético nacional por la vía electronuclear; las ciencias nucleares han evolucionado y alcanzado grandes logros, a pesar de los limitados recursos con los que cuenta el país. Este proceso histórico no ha sido debidamente estudiado y divulgado entre el público no vinculado al sector nuclear; por lo que merece ser analizado desde un punto de vista objetivo, actual y no sensacionalista. Quizás por desconocimiento de la población, que generalmente percibe el término "nuclear" asociado a armas o centrales nucleares, las

aplicaciones y la labor de los profesionales en esta área de la ciencia en Cuba, suelen pasar inadvertidos. Por ello, el presente trabajo tiene como objetivo sistematizar sobre los procesos referentes a la evolución de las ciencias y tecnologías nucleares en Cuba a partir de 1959, teniendo en cuenta el escenario histórico y político que determina los esfuerzos hacia los que se encaminan las aplicaciones nucleares en cada período histórico, así como su trascendental contribución al desarrollo sostenible del país, desde los primeros años de la Revolución hasta finales del siglo XX.

**Palabras clave:** Tecnologías Nucleares; Ciencias Nucleares; Programa Nuclear Cubano; Desarrollo Sostenible Y Sustentable.

## INTRODUCTION

After the triumph of the Revolution on January 1, 1959, one of the main efforts to improve the situation in Cuba was the creation of an adequate scientific and technical infrastructure, which in turn would allow for the construction of a high-quality health and education system, as well as the improvement of services, the economy, and the national defense system. By this date, the use of nuclear energy was already well established worldwide, and even as early as 1953, Fidel Castro had envisioned a nuclear future for the island, leaving testimony to this in his self-defense speech "History Will Absolve Me," when he stated:

"(...) the possibilities of bringing electricity to every corner of the island are greater today than ever before, since the application of nuclear energy to this branch of industry is now a reality".[1]

Fidel saw nuclear energy as a powerful tool to address the national electricity problem. So, the assimilation and application of atomic technologies became one of the objectives pursued after the establishment of the revolutionary government. These expectations were fulfilled, mainly thanks to collaboration with the Soviet Union and the International Atomic Energy Agency (IAEA).

One of the high points of nuclear development in our country was undoubtedly during the so-called Cuban Nuclear Program, which, although it did not achieve its fundamental objective from an atomic energy point of view, it left behind several institutions and professionals specialized in the use of nuclear techniques, who have played a key role in training new generations, making it possible for nuclear science and technology to continue to be applied today for the sustainable development of the country.

Given Cuba's outstanding achievements in the nuclear field and the current applications of atomic science and technology, this research project aims to systematize the processes related to the evolution of nuclear science and technology in Cuba since 1959, taking into account the historical and political context that determines the efforts toward which nuclear applications are directed in each historical period, as well as their significant contribution to the sustainable development of the country, from the early years of the Revolution to the end of the 20th century.

## DEVELOPMENT

One of the first steps toward achieving adequate scientific and technical development in the country was the founding of the Cuban Academy of Sciences on February 20, 1962, under the presidency of Antonio Núñez Jiménez, which promoted the creation of centers such as the National Institute of Oncology and Radiobiology (INOR), the National Center for Scientific Research (CNIC), and the Institute of Animal Science (ICA), which were pioneers in the country in the use of ionizing radiation in biomedical trials.[2]

Despite these significant achievements in national scientific development, from a nuclear point of view, the event that marked the early years of the Revolution was undoubtedly the October Crisis or Missile Crisis, whose fundamental cause lay in the intergovernmental agreement between the USSR and the Cuban government to install nuclear weapons on the island; However, Cuban researcher Fabián Escalante points out that, given the aggressive policy of the United States towards Cuba, a crisis in the Caribbean was inevitable, with or without missiles.[3]

Following the Bay of Pigs invasion and the constant subversive acts that had increased as part of Operation Mongoose since its approval on March 16, 1962, the threat of another invasion loomed over the island.[4] In this context, on May 29, 1962, a Soviet delegation headed by Sharaf Rashidov arrived in Havana with a mission entrusted to it by Soviet President Nikita Khrushchev to propose to the Cuban government the installation of medium- and intermediate-range missiles as a deterrent against possible aggression by the US government.[5]

In his response to the proposal, Fidel argued that Cuba did not need such weapons to defend its sovereignty, as it had already demonstrated at Girón, but that he would accept the installation of the missiles as a sign of solidarity with the USSR, as an agreement of this nature would strengthen the socialist bloc.[5]

Between July and October, many agreed weapons were deployed in the country, along with the necessary equipment and specialists for their installation. Soviet troops in Cuba reached a total of 43 000 men.[6] The

entire process was carried out with the utmost discretion, as proposed by the Moscow government and even against Fidel Castro's suggestion to make the agreement public to legitimize it in the eyes of public opinion.[5] Khrushchev had committed to deploying 24 medium-range (approximately 1 690 km) R-12 ballistic missiles with a nuclear yield of between 1,3 and 2,3 Mt, and 16 intermediate-range R-14 missiles (approximately 3 380 km), which doubled the range and power of the R-12s;[7] in addition to motorized infantry regiments, anti-aircraft rocket divisions, and submarines with atomic missiles.[5]

On October 14, 1962, US intelligence services detected the presence of offensive weapons and launch platforms being built in San Cristóbal, west of Havana. The US government could not tolerate such a threat, so on October 22, 1962, President Kennedy publicly declared the establishment of a quarantine and a "naval blockade" around the island of Cuba, deploying warships and aircraft in the Caribbean Sea to block the passage of Soviet ships and prevent the shipment of weapons to Cuba. Kennedy also authorized offensive action against the USSR if it did not back down from its "Operation Add" or use the missiles already installed on the island.[6,8]

This situation put the entire world on a war footing, prompting Khrushchev to begin negotiations with Kennedy. These negotiations resulted in an agreement to withdraw the weapons and military advisers deployed in Cuba in exchange for the United States lifting the blockade of the island and removing the obsolete medium-range missiles deployed in Turkey, as well as promising not to invade Cuba. The Cuban government's opinion was not considered in the negotiations, and Fidel Castro's dissatisfaction was palpable.[6,8]

The situation during the October Crisis was truly overwhelming. The quarantine decreed by Kennedy involved deploying 16 destroyers, three cruisers, an anti-submarine aircraft carrier, and six mother ships stretching from Florida to Puerto Rico. The US ambassadors in Guinea and Senegal asked their respective governments to deny landing permission to Soviet aircraft stopping in those countries on their way to Cuba. This request was accepted by both nations.[9] On the Soviet side, according to former military leaders of the USSR, during the crisis, its forces in Cuba had 162 nuclear warheads, in addition to four submarines that were tracking US ships in the vicinity of the island and were equipped with nuclear-tipped torpedoes.[7] These figures demonstrate the magnitude of the conflict brewing and the need to bring it to a peaceful end.

Fidel Castro did not stand idly by and ordered, starting on the 27th, to open fire on any enemy aircraft flying at low altitude. That same day, a U-2 plane was shot down in the Banes area. This firm and unexpected response shook the Kennedy administration, which did not hesitate to accept the USSR's proposal. On October 28, the Soviet government issued an order to cease construction of the missile sites and dismantle the facilities already deployed. This decision was not consulted with or officially communicated to the Cuban government. Fidel expressed his indignation at how the negotiations had been handled and at the fact that "Cuba's missiles had been exchanged for those in Turkey."[6]

In 1962, Cuba became the scene of one of the most tense moments of the Cold War. Both President Kennedy and the Soviet government made the accepted decision to find a peaceful way to resolve the situation, showing a forward-looking and rational attitude, considering the severe damage that the start of a nuclear war would cause to both countries and the world.[10] However, the treatment of the Cuban government was reprehensible and outrageous. The agreements were not fully complied with by the US government, which continued its aggression against Cuba, not through military confrontations such as the mercenary invasion in Girón, but through smear campaigns, sabotage, attacks, and, above all, the economic blockade, which continued to hinder the country's development.

**Progress achieved in the first half of the 1970s. Cuban Nuclear Program**

In the 1970s, the Institute of Nuclear Physics (IFN), founded by Fidel in January 1969,[11] played a leading role as the driving force behind the nuclear initiative through various research projects, but with the primary objective of ensuring the academic training of specialists.[11,12] Through collaboration agreements with the International Atomic Energy Agency (IAEA), the United Nations Development Program (UNDP), and the USSR, the IFN promoted the installation of a subcritical reactor, radiochemical facilities, gamma radiation sources, and neutron spectrometry analyzers. The CNIC also began implementing nuclear techniques in oil exploration.[11]

In 1976, as part of the intergovernmental agreement between Cuba and the USSR, it was agreed to build the first nuclear power plant in Latin America in Juraguá, in the province of Cienfuegos, which led to the structuring of the Cuban Nuclear Program, which outlined five main areas of focus: nuclear energy, the creation of a radiation protection and nuclear safety system, the widespread introduction of atomic techniques in various sectors, the promotion of basic and applied research, and the comprehensive training of the necessary personnel.[2] The plant would have four Soviet VVER pressurized water reactors, which used water as a coolant and a neutron moderator. Construction of the first reactor began in 1983 and the second in 1985. The reactors would be of the original VVER-440/V-318 model, designed to be earthquake-resistant, with a simple cylindrical reinforced concrete containment and a power output of 417 MW.[13,14] With a three-year cycle, the fuel to be used would be uranium (IV) oxide slightly enriched between 2,4 and 4,4 % of 235U.[15,16]

With the creation in 1980 of the Cuban Atomic Energy Commission (CEAC) and the Executive Secretariat for

Nuclear Affairs (SEAN), the country took an essential step in organizing efforts to assimilate nuclear technologies for various peaceful uses, in line with the objectives set out in the Cuban Nuclear Program. The CEAC was responsible for coordinating and controlling scientific activities in the country in the nuclear field and providing advice to the state on policy in this area. At the same time, the SEAN was responsible for implementing the approved policy and developing the necessary scientific and technical infrastructure and human capital.[16]

Despite multiple efforts to promote the Cuban Nuclear Program, its primary objective, nuclear energy, became virtually impossible to achieve after the fall of the socialist camp and the disintegration of the USSR. The construction of a nuclear power plant requires significant investments. Still, after the disappearance of the Soviet Union, the lack of resources and budget led the Cuban government to decide in 1992 to abandon the construction of what would have been "the project of the century." Although two of the four reactors had already been built, essential components still had to be installed, and the nuclear fuel had not been delivered.[2]

**Applications of nuclear science in the country as part of the Cuban Nuclear Program (1976-1992)**

During this period, several centers were founded whose primary focus was on research and applications of nuclear science for peaceful uses. However, several institutions have also recognized nuclear technologies' potential and begun to apply them in different sectors such as agriculture and environmental studies. Of course, in the industrial and medical sectors, where nuclear technologies had already been assimilated since the 1940s, atomic technologies continued to be promoted in increasingly promising areas subject to intense scientific research.

To fulfill one of the priority objectives of the Cuban Nuclear Program: radiological safety, the Center for Radiation Protection and Hygiene (CPHR) was established in 1985 as the technical center for all radiological monitoring in the country. Soviet advice was essential in the early stages of its development, enabling the training of young personnel in the most rigorous radiation protection measures and the most accurate dosimetric methods available at the time, to guarantee the physical integrity of both occupationally exposed personnel and the population.[17]

In 1991, the National Nuclear Safety Center (CNSN) was founded as the regulatory body responsible for evaluating compliance with radiation safety measures in institutions where nuclear technologies were used. Since the emergence of the CNSN, strategies to ensure nuclear and radiation safety have been refined in the country, establishing a legal and regulatory framework for using atomic energy. By the standards recommended by the IAEA, Decree-Law No. 207 of 2000 "On the use of nuclear energy" was approved, establishing the requirements to be met in premises where radioactive substances are handled, the transport of these materials, waste management, notification and authorization for the performance of these practices, as well as inspection and control procedures.[18,19]

On October 28, 1987, the Center for Technological Applications and Nuclear Development (CEADEN) was inaugurated,[11,19] with the participation of Fidel Castro and the then Director General of the IAEA, Hans Blix.[20] Since its inception, the center has been actively involved in applied research, technology assimilation, and providing scientific and technical services.[11,19] In 1988, CEADEN achieved commendable results in the development of techniques for the preparation of labeled compounds. That year, it began preparing the gamma variant of ATP labeled with 32P, which was supplied to the Center for Genetic Engineering and Biotechnology (CIGB) for metabolic studies. In addition, the center supplied insulin labeled with 125I to the Hermanos Ameijeiras Hospital for radiodiagnostics and diabetes studies.[21] Its research covers diverse fields such as condensed matter physics, analytical chemistry, radiochemistry, radiobiology, nuclear electronics, optics, precision mechanics, and materials science.[19]

During this period, INOR promoted nuclear applications in medicine. Thanks to international collaboration agreements through the UNDP, the center had a gamma camera and a supply of radionuclides, which enabled the development of research and the provision of diagnostic and therapeutic services for oncological, cardiovascular, and neurological diseases, among others.[12]

The industrial sector was among the most favored, mainly to meet the increasingly high expectations for electronuclear energy. Other efforts were also added to this, mainly in leak detection using X-ray and gamma-ray techniques [18] and applying nuclear techniques in oil exploration.[22,23] Since the early 1990s, numerous results have been reported on evaluating the multi-element composition of oil and natural gas reservoirs in the northern part of the Havana-Matanzas, Martín Mesa, and Pina area.[24]

An irradiator with 12 sealed 60Co sources was installed at the National Center for Agricultural Health (CENSA), which began operating in 1985.[25,26] In March 1987, the Food Irradiation Plant was inaugurated, where different agricultural products have been irradiated to eliminate pests and delay ripening. However, a decade after its foundation, the plant interrupted its services due to low production activity and technological modifications needed to meet national and international market requirements. Since 2005, the Agency for Nuclear Energy and Advanced Technologies (AENTA) has been developing a strategy in collaboration with the IAEA and the CPHR for the removal of disused sources, and new 60Co sources have been installed at the plant,

which reopened in 2019.[27,28]

Studies have also been conducted to evaluate nutrient uptake and biodistribution in plants and fertilizer efficiency using radiotracers labeled with 15N, 32P, and 14C. Inducing crop mutations to achieve better nutritional properties and increase their resistance to pests is another field of study that has attracted considerable interest in the agricultural sector.[22,29]

Radiotracers have played an important role in environmental studies, analyzing residence times to determine the flow rate of river systems and groundwater basins. Studies have also been reported on the isotopic composition of wells and springs in the Pinar del Río and Matanzas areas.[16]

In 1989, the National Environmental Radiological Surveillance Network was established under the direction of the CPHR to detect any radiological anomalies occurring in the national territory due to nuclear accidents on a regional or global scale.[17] The network has undergone automation and improvement processes to increase its response capabilities and the accuracy and precision of its monitoring.[30,31,32]

## CONCLUSIONS

The advances made in the nuclear field in Cuba since the early years of the Revolution, based on Fidel Castro's initiative and collaboration with the USSR, were characterized.

The scientific and technological development achieved during the Cuban Nuclear Program and the direction taken by nuclear sciences after the collapse of the USSR were analyzed.

The international influence on Cuban nuclear development since 1991 was evaluated, mainly through collaboration agreements with the IAEA.

The impact of nuclear science and technology in Cuba on industry, agriculture, medicine, and environmental studies from 1959 to the end of the 20th century was assessed.

## REFERENCES

1. Castro Ruz, F. (1953). La historia me absolverá.

2. Castro Díaz-Balart, F. (2014). La física nuclear en Cuba: apuntes para una historia. Nucleus, 56.

3. Guerra, P. M., Milanés, E. (2022, October 7). Con misiles o sin misiles habría crisis de octubre. Cuba Periodistas.

4. Escalante Font, F. (2008). La Guerra Secreta: Proyecto Cuba. Editorial de Ciencias Sociales.

5. Évora Capote, I. (2012). Crisis de Octubre. Cuba y su juventud con el escudo: memorias sobre la artillería. Editorial Universitaria.

6. Rodríguez Díaz, A. R., Milián Rosales, L. de la C., Delgado Corrales, B. (2018). Fidel Castro y la crisis de octubre. Varona, Revista Científico-Metodológica.

7. Linares Martínez, A. (2009). Lo que revelan los archivos desclasificados sobre la crisis de los misiles en Cuba y la definición de la Guerra Fría. Revista de Historia y Ciencias Sociales, 16, 82–106.

8. Capote, R. A. (2018). Crisis de octubre: los cinco puntos de la dignidad. Granma.

9. Molla, Luis., Pasamontes, J. C. Cuba, 1962: los misiles que estremecieron al mundo.

10. Carbone, V. L. (2006). Cuando la Guerra Fría llegó a América Latina: la política exterior norteamericana hacia Latinoamérica durante las presidencias de Eisenhower y Kennedy (1953-1963). Centro Argentino de Estudios Internacional.

11. Sánchez Colina, M., Baracca, A., Cabal Mirabal, C., Pentón Madrigal, A., Renn, J., & Wendt, H. (2019). Historia de la física en Cuba (siglo XX). Max Planck Institute for the History of Science.

12. Baracca, A., Fajer, V., & Henríquez, B. (2005). El despegue de la física en Cuba desde 1959 hasta la década de los 70: un enfoque abarcador. RUISF.

13. Castro Díaz-Balart, F. (1990). La energía nuclear en Cuba: factor imprescindible para el desarrollo. Boletín Del OIEA.

14. Milhem, M., Reibell, M., & Dejeux, M. (1992). Descriptions des VVER. SFEN.

15. Smetana, J. (2014). Combustible nuclear para agua a presión. Reactores Nucleares.

16. Castro Díaz-Balart, F. (1997). Energía Nuclear: ¿peligro ambiental o solución para el siglo XXI? (1ra ed.). Ediciones Mec Grafic S.A.

17. Walwyn Salas, G., González Mesa, J. E., Molina Pérez, D., Dayana, R., Machado,

18. G. M., López Bejerano, I. M., Fernández Gómez, C. C., Ramos, O. G., Lima, M. M., Salgado Mojena, R., Ramos Valdés, M., Peralta Vital, J. L., Castro Soler, A., González Rodriguez, N., Cardenas Herrera, J. & Tamayo García, J. A. (2020). CPHR: 35 años al Servicio de la Protección Radiológica, la Salud y el Medio Ambiente. Nucleus, 67.

19. Guillén Campos, A. (2016). 25 años del Centro Nacional de Seguridad Nuclear. Nucleus, 60.

20. Marrero García, M., & Sanabria Molina, I. (2010). Implementación de un sistema de gestión de la calidad en el Centro Nacional de Seguridad Nuclear de la República de Cuba. Nucleus, 48.

21. Herrera Palma, V., Hernández Torres, D., & Sendoya Puente, F. (2023). Aportes de los servicios científico-técnicos del CEADEN a la economía nacional. Nucleus, 73.

22. Organismo Internacional de Energía Atómica. Hans Blix nombrado Director General. (1981).

23. Días García, A. (2017). El Centro de Estudios Aplicados al Desarrollo Nuclear (CEADEN) en ocasión de su 30 aniversario. Anales de La Academia de Ciencias de Cuba, 7.

24. Griffith, J., Desdín, L. F., Rodríguez, R. (1997). Experiencias de las aplicaciones de las técnicas nucleares en la industria cubana.

25. Rodríguez Martínez, N., Montero Cabrera, M. E. (1997). Avances cubanos en la aplicación de las técnicas nucleares en la prospección de petróleo.

26. Llanes Rodríguez, M., Rodríguez Perdomo, Y., Benítez Navarro, J. C., Salgado Mojena, M., Fraga Acosta, D., Soto Álvarez, E., Pérez Reyes, Y., Soler Roger, D. M., & Abreu Méndez, Y. (2011). Desmantelamiento del irradiador autoblindado Gammacell 500. Nucleus, 50.

27. Prieto Miranda, E., & Chávez Ardanza, A. (2023). La tecnología de irradiación en el Centro de Aplicaciones Tecnológicas y Desarrollo Nuclear (CEADEN). Resultados y perspectivas. Nucleus, 73.

28. Planta de Irradiación de Alimentos en Cuba gestiona sus fuentes en desuso de forma segura, liderado por expertos del CPHR. (2022).

29. León, V., Pérez, I. P., Dorado, M., Gutiérrez, L., & Herrería, M. E. (2004). Tres décadas de aplicaciones de las técnicas nucleares al desarrollo de la agricultura cubana. Revista Agrotecnia de Cuba.

30. Isasi, E. M., & Abreu Ferrer, S. (1983). Influencia del tratamiento mutagénico de un híbrido intervarietal de frijol común (Phaseolus vulgaris).

31. Domínguez Ley, O., Kalber, O., Capote Ferrera, E., Carrazana González, J. A., Manzano de Armas, J. F., Alfonso Abad, D., Prendes Alfonso, M., Zerquera, J. T., Caveda Ramos, C. A., Fabelo Bonet, O., Cartas Águila, H., Leyva Fernández, J. C., & Montalvan Estrada, A. (2005). Automatización del monitoreo en tiempo real de la tasa de dosis absorbida en aire debido a la radiación gamma ambiental en Cuba. Nucleus, 37.

32. Domínguez Ley, O., & Ramos Viltre, E. O. (2006). Incorporación de una estación radiológica cubana a la Red Global de Isótopos en Precipitaciones.

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